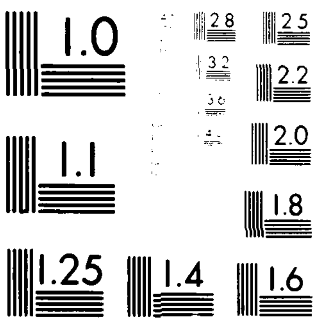
AD-A115 321 DAVID W TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CE--ETC F/G 13/10
THE DESIGN OF A FIXED-PITCH SKEWED PROPELLER FOR A CABLE LAYING--ETC(U)
MAY 82 N R STARK
UNCLASSIFIED DTNSRDC/SPD-1020-01 NL

1 of 1
AD A
115321

END
DATE
FILMED
07-82
DTIC



MICROCOPY RESOLUTION TEST CHART

DTNSRDC/SPD-1020-01

(12)

DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084

THE DESIGN OF A FIXED-PITCH SKEWED PROPELLER FOR A CABLE LAYING REPAIR SHIP (T-ARC)

BY

NICHOLAS R. STARK

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

SHIP PERFORMANCE DEPARTMENT

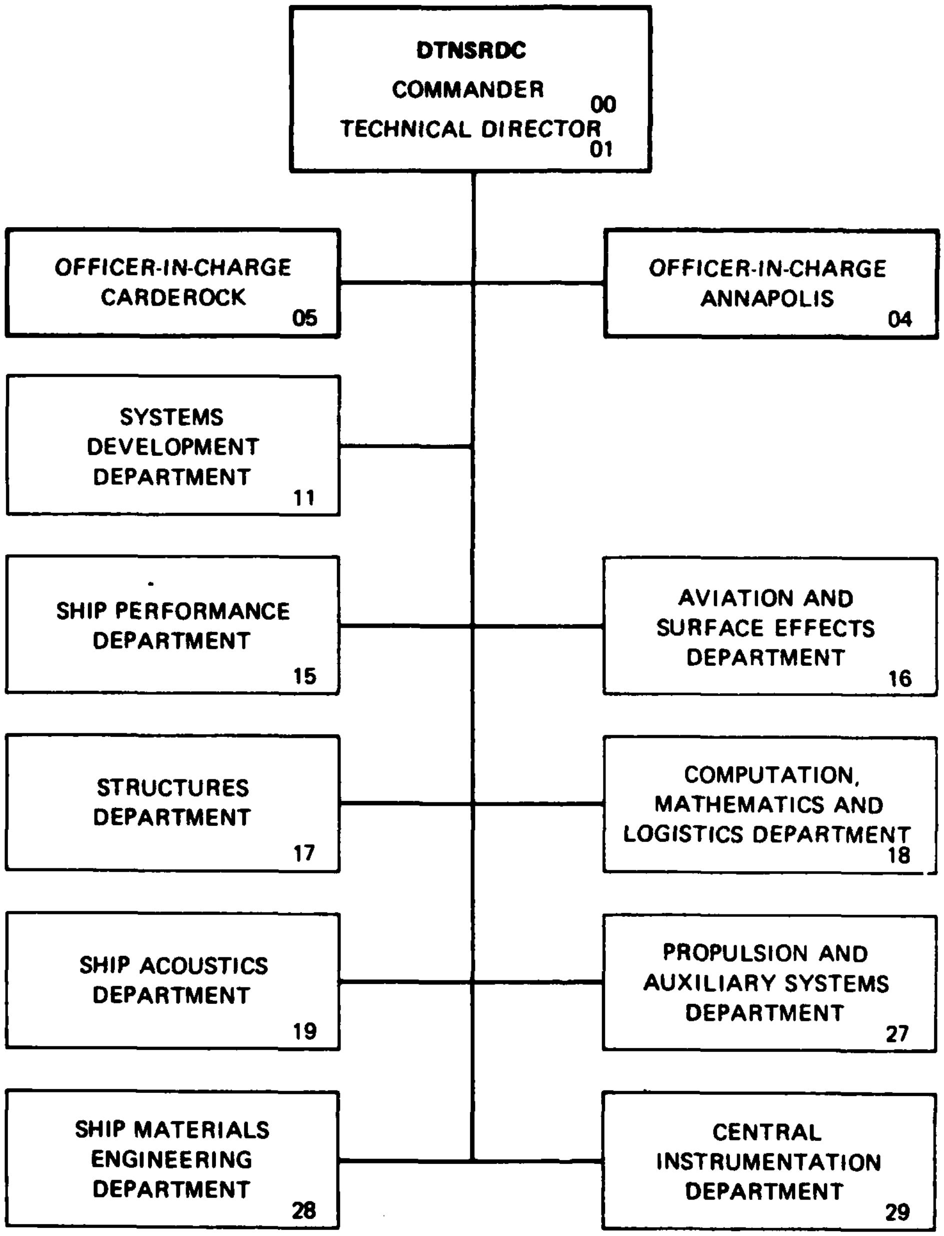
MAY 1982

DTNSRDC/SPD-1020-01

THE DESIGN OF A FIXED-PITCH SKEWED PROPELLER FOR A CABLE LAYING REPAIR SHIP (T-ARC)

NDW-DTNSRDC 5602/30 (2-80)
(supersedes 3960/46)

MAJOR DTNSRDC ORGANIZATIONAL COMPONENTS



UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER DTNSRDC/SPD-1020-01	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) The Design of a Fixed-Pitch Skewed Propeller for a Cable Laying Repair Ship (T-ARC)		5. TYPE OF REPORT & PERIOD COVERED Departmental/Final
		6. PERFORMING ORG. REPORT NUMBER DTNSRDC/SPD-1020-01
7. AUTHOR(s) Nicholas R. Stark		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS David W. Taylor Naval Ship Research and Development Center Bethesda, Maryland 20084		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 1544-338 1544-343
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Sea Systems Command, Code 521 Washington, D.C. 20362		12. REPORT DATE May 1982
		13. NUMBER OF PAGES 51
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release: Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Propeller, Lifting Line, Lifting Surface, Stress

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The design process is presented for a fixed-pitch propeller for a Cable-Laying Repair Ship (T-ARC). The design specifications required that sufficient thrust be provided at bollard and other low-speed conditions and that the endurance speed at 80-percent power be 15 knots. The effects on performance of various design parameters are also considered

(Continued to next page)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

The propeller is 13 feet (3.936 m) in diameter and is designed to turn at 145 rpm at full power and 135 rpm at endurance speed. Calculations indicate that this propeller will perform satisfactorily at all required conditions. However, cavitation will be present at both endurance and full-power conditions and, if more than 6-percent margin in effective power is required, 15 knots will not be attainable at 80-percent power. Nearly twice the required thrust will be available at the low-speed conditions.

Model experiments with the final hull and appendages, and the design Propellers 4761 and 4762, indicated a reduction in EHP and wake fraction and an increase in thrust deduction compared to the data from the original powering tests with a preliminary hull shape and stock propellers. Comparison of the predicted performance of the design propeller with its experimental performance showed agreement within 2.2 percent for speed at the same rpm.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

NOTATION

A	Area of blade section
A_E	Expanded area, $Z \int_{r_h}^{R} c\,dr$
A_0	Disk area of propeller, πR^2
C_A	Correlation allowance
C_D	Drag coefficient of section
C_L	Lift coefficient of section at ideal angle of attack, $L/[(1/2)\ \rho V_r^2 c]$
C_{PS}	Power coefficient based on ship speed
C_{PSI}	Inviscid power coefficient based on ship speed
C_{PT}	Thrust power coefficient, $\int_{x_h}^{1}(1-w_x)(1-\varepsilon\tan\beta_I)(dC_{TSi}/dx)dx=(1-w_T)\{T/[(\rho/2)\pi R^2 V^2]\}$
C_{PTI}	Inviscid thrust power coefficient, see equation for C_{PT} with $\varepsilon = 0$
C_{Pmin}	Minimum pressure coefficient
C_{Th}	Thrust loading coefficient, $T/[(1/2)\ \rho V_A^2 A_0]$
C_{ThS}	Thrust loading coefficient based on ship speed, $T/[(1/2)\ \rho V^2 A_0]$
C_{ThSI}	Inviscid thrust loading coefficient based on ship speed
c	Section chord length (subscript indicates the nondimensional radius)

D Propeller diameter

EAR Expanded area ratio, A_E/A_O

F Factor for estimating local angles of attack, $1/[1 + 2\pi\tan(\beta_I-\beta)/C_L]$

f Camber of section

f_{2D} Camber required to produce specified lift coefficient at ideal angle of attack in two-dimensional flow

G Nondimensional circulation, $\Gamma/\pi DV$

g Acceleration due to gravity

H Hydrostatic head at shaft centerline minus vapor head

J Advance coefficient, V_A/nD

K_Q Torque coefficient, $Q/\rho n^2D^5$

K_T Thrust coefficient, $T/\rho n^2D^4$

L Local effective lift per unit area, $(1/2)\rho {V_r}^2 C_L$

n Propeller revolutions per unit time

$(P/D)_I$ Propeller section hydrodynamic pitch ratio, $\pi x\tan\beta_I$

P Propeller section pitch

P_D Delivered power at propeller, $2\pi nQ$

P_E Effective power, $R_T V$

P_S Power delivered to shaft aft of gearing and thrust block

p Local pressure

p_V Vapor pressure

Q Propeller torque

R Propeller radius

R_n Reynolds number of propeller, at 70 percent radius,

$$c_{0.7}\left[V_A^2 + (0.7\pi nD)^2\right]^{1/2}/\nu$$

R_T Total resistance of hull

r Radial distance

r_h Radius of hub

T Propeller thrust

t Maximum total thickness of blade section

t Thrust deduction fraction, $(T-R_T)/T$

U_A Axial induced velocity at lifting line

U_T Tangential induced velocity at lifting line

V Ship speed

V_A Speed of advance of propeller, $V(1-w_T)$

V_r Resultant circumferential average inflow velocity to blade section

V_x Local longitudinal wake velocity, positive aft

V_T Local tangential wake velocity, positive counterclockwise looking upstream

w_T Taylor wake fraction determined from thrust identity

w_x Local wake fraction

x Nondimensional radial distance, r/R; correlation factor for EHP

x,y,z Coordinate axes along which bearing forces and moments are resolved

Z Number of blades

α Section equivalent angle of attack in two-dimensional flow

α_I Ideal angle of attack required for shock-free entry in two-dimensional flow

β Circumferential mean advance angle, $\tan^{-1}\{V(1-w_x)/(\pi xnD)\}$

β_I Hydrodynamic flow angle

Γ Circulation about blade section

τ_c Burrill thrust coefficient

η Estimated propeller efficiency, C_{PT}/C_{PS}

η_D Propulsive efficiency, P_E/P_D

η_I	Estimated inviscid propeller efficiency, C_{PTI}/C_{PSI}
θ_W	Wake position angle about propeller axis in propeller plane, measured from vertical upward, positive counterclockwise looking upstream
θ_S	Skew angle in the projected plane measured from a radial line through the midchord of the section at the hub to the radial line through the midchord of the section at the local radius, positive in direction opposite to ahead rotation
ρ	Mass density of water
ρ_p	Mass density of propeller
ν	Kinematic viscosity
σ	Cavitation number based on vapor pressure, $2gH/V_r^2$
σ_{HVM}	Hencky-Von Mises Stress, $\sqrt{[(\sigma_{P1} - \sigma_{P2})^2 + \sigma_{P1}{}^2 + \sigma_{P2}{}^2]/2}$
σ_L	Cavitation number based on vapor pressure, local wake and head, $2gH_L/[V_X^2 + (2\pi nr + V_T)^2]$
σ_p	Maximum principal stress

Subscripts:

E	Value at endurance condition (80 percent of full power)
FP	Value at full-power condition

Superscripts:

–	Time-average value
~	Unsteady value

ENGLISH/SI EQUIVALENTS

ENGLISH	SI
1 foot	0.3048 m (meters)
1 knot	0.5144 m/sec (meters per second)
1 pound (force)	4.4480 N (Newtons)
1 horsepower	0.7457 kW (kilowatts)
1 long ton	1.016 tonnes, 1.016 metric tons, or 1016 kilograms
1 pound (force) per square inch	6.895 kPa (kilopascals)

ABSTRACT

The design process is presented for a fixed-pitch propeller for a Cable-Laying Repair Ship (T-ARC). The design specifications required that sufficient thrust be provided at bollard and other low-speed conditions and that the endurance speed at 80-percent power be 15 knots. The effects on performance of various design parameters are also considered.

The propeller is 13 feet (3.963 m) in diameter and is designed to turn at 145 rpm at full power and 135 rpm at endurance speed. Calculations indicate that this propeller will perform satisfactorily at all required conditions. However, cavitation will be present at both endurance and full- power conditions and, if more than 6-percent margin in effective power is required, 15 knots will not be attainable at 80-percent power. Nearly twice the required thrust will be available at the low-speed conditions.

Model experiments with the final hull and appendages, and the design Propellers 4761 and 4762, indicated a reduction in EHP and wake fraction and an increase in thrust deduction compared to the data from the original powering tests with a preliminary hull shape and stock propellers. Comparison of the predicted performance of the design propeller with its experimental performance showed agreement within 2.2 percent for speed at the same rpm.

ADMINISTRATIVE INFORMATION

The work reported herein was funded by the Naval Ship Engineering Center (NAVSEC 6144 now NAVSEA 521), NAVSEC Work Request N65197-78 WR82286 and WR92009. The work was performed under David W. Taylor Naval Ship Research and Development Center (DTNSRDC) Work Unit Numbers 1544-338 and 1544-343.

The English system of units was used in the original calculations presented in this report. Therefore, all data are presented in English units. However, the International System (SI) of metric units is shown in the text in parentheses following the English units.

INTRODUCTION

The Naval Sea Systems Command (NAVSEA) tasked DTNSRDC to design a fixed-pitch propeller for a Cable-Laying Repair Ship (T-ARC). The preliminary design for the propeller had been performed by Hydronautics, Inc.[1*], using the ship particulars and hull lines presented in Table 1 and Figure 1, respectively.

---

*References are listed on page 13.

The wake developed from this hull configuration is presented in Figure 2. The lack of symmetry is the result of the strut and stern thrusters, while the velocity deficit is the result of the enclosed inclined shaft and the strut arrangement.

The propeller design at DTNSRDC was to be based upon conclusions established by Hydronautics, Inc., and was to provide final propeller offsets for construction. The basic design variables such as number of blades, diameter, and area ratio were to be evaluated for expected ship design variation and the related changes in the design specifications.

NAVSEA set the following specifications for the design of the propeller:

1. The T-ARC will have two propellers with outboard rotation to reduce the risk of fouling with the cable even though inboard rotation gives higher efficiency.
2. The propellers will be driven by electric motors with a torque limit of 260,000 ft-lbs for each propeller.
3. The number of propeller blades shall be four or five.
4. The diameter, D, will be 13 ft (3.963 m) unless it is advantageous to change it. The maximum submergence of blade tips placed at the baseline of the ship results in a tip clearance from the hull of 0.23D.
5. The propeller shall turn nominally at 150 rpm at full power.
6. The full power, or maximum available delivered power, will be 5000 horsepower per shaft. The ship must make 15 knots at 80 percent of full power.
7. Thrust breakdown due to cavitation shall not occur at design draft and trim conditions at full power, based on resistance predictions including still air drag and specified margin on effective power. No margin above this full-power point is specified for thrust breakdown, and this requirement can be changed, if necessary, to obtain 15 knots at 80-percent power.
8. The propeller shall provide a minimum of 50,000 pounds of thrust in the range of 0 to 1 knot.
9. The thickness of the propeller blades shall meet the requirement of American Bureau of Shipping (ABS) Class C Ice Strengthening. The blade mean and unsteady stresses shall be below 12,500 psi and 6,250 psi, respectively, based on beam theory.

10. The model resistance data, with a correlation allowance, C_A, of 0.0005, shall be used (see Table 2); this includes revisions to the model effective horsepower to account for still air drag and a 6-percent power margin.
11. The model wake data in Reference 2 are to be used (see Figure 2). The propeller drag coefficient used shall be based on the blade section Reynolds number and the ITTC friction line.

This report describes the design process for the propeller, including consideration of thrust breakdown at full power in the free running and bollard conditions, time-average and fluctuating stresses, and propeller-excited vibratory forces. The report also presents the geometry of the model propeller. Appendix A presents the final geometry as corrected to meet ABS Class C Ice Strengthening Requirements.

The design detailed herein was evaluated for propulsion performance by model experiments. The results of these model experiments were reported in Reference 3. The final geometry reported in Appendix A was not evaluated at model scale.

DESIGN OF PROPELLER

The propeller preliminary design was completed by Hydronautics, Inc.[1], before the detailed design was undertaken at DTNSRDC. This preliminary design yielded approximate values of diameter, rpm, delivered power, and margin to thrust breakdown at both free-running and bollard conditions.

The major characteristics considered in the final design of the propeller were:

Radial Distribution of Loading: The radial distribution of loading corresponds to the Lerb's optimum distribution, which results from lifting-line theory calculations for minimum shaft horsepower, taking into account blade section viscous drag. The low inception speeds for tip-vortex and hub-vortex cavitation that result from the use of Lerb's optimum load distributions were not considered to be objectionable.

Skew: The magnitude and distribution of skew were selected from considerations of propeller-induced vibration/excitation. Calculations were performed, using unsteady lifting-surface theory and the wake measured behind the model hull, to determine the pertinent components of unsteady bearing forces and moments.

Rake: The magnitude and distribution of rake were selected to provide the blade adequate clearance relative to the shaft strut and rudder.

Blade Width: The magnitude and distribution of blade area were determined from the standpoint of blade surface cavitation and consideration of propeller-induced vibration/excitation. Blade area is sufficient to ensure that thrust breakdown does not occur at full power. Blade area was also used to reduce the propeller-induced vibration/excitation in lieu of additional skew.

Thickness, Camber, and Pitch: The magnitude and distribution of blade thickness were determined by ABS Class C Ice Strengthening Requirements. The final camber and pitch distributions were determined using lifting-surface calculations for NACA 66 thickness form and an NACA a = 0.8 mean line. The stresses in the final blade configuration were calculated by finite element methods.

Design calculations were performed to determine the effect on propeller performance of the major variables listed above. However, most of the areas are closely interrelated, making iterations between steps necessary. These are discussed in more detail in the following sections.

PRELIMINARY DESIGN

In the preliminary design, the major propeller parameters, such as diameter and rotational speed, are determined from considerations of vibration and efficiency so the propeller will be compatible with the ship's performance requirements and installed propulsion machinery. The preliminary design was conducted by Hydronautics, Inc.[1], before the start of the current detailed design. Based on the results of Reference 1 and the design requirements, the design was considered to be straightforward. DTNSRDC, therefore, chose the following initial blade geometric characteristics:

1. The chord-diameter ratio distribution of the Troost series propellers (Figure 3) was used.
2. The initial thickness-chord ratio distribution was that defined in Eckhardt and Morgan[4] (Figure 4, where the dashed line is dimensional and the solid line, nondimensional). The required ABS rule for ice strengthening was applied only to the final design.
3. The skew and rake were set at zero. These were to be adjusted later if necessary.

The propeller design was begun using the above blade characteristics. The design point was chosen to be that determined in the preliminary design investigation and the experimental powering data was used as input to the lifting-line calculations.[5]

However, during the detailed design process, modifications were made to the ship afterbody and appendages to improve maneuverability, which resulted in a 7-percent reduction in the EHP. Only the final data are shown in Table 2. This and the need to reduce the predicted unsteady forces to less than 1 percent for both the unsteady thrust and torque for the present design configuration combined to cause the following changes from the initial simple geometry:

1. Linear skew was added to reduce the unsteady forces.
2. The blade area ratio was increased to aid in reducing the unsteady forces.
3. The chord distribution at the root was modified to keep the hub size to a minimum to prevent shafting problems with regard to propeller weight.
4. Rake was added to position the blades clear of both rudder and hull.

During the first phase of the design process, the preliminary design point was re-evaluated to define the sensitivity of the design to the various parameters and as a check of Hydronautics, Inc., results. The parameters varied were rpm, area ratio, diameter, and blade number. The results of these variations are presented in Table 3. The design variations were investigated for the maximum shaft-horsepower (including the 6-percent margin) condition, rather than 15 knots, 80-percent power condition. The hydrodynamic pitch distribution was that corresponding to Lerbs' optimum.

The rpm was varied to establish the maximum with the chosen geometric and preliminary design characteristics. The variation of propulsive coefficient is presented in Figure 5 as a function of rpm. The optimum rpm is 150, which is in agreement with preliminary design results; therefore, 150 rpm was used when investigating other design variations. Figure 5 shows that the design is relatively insensitive to variation of rpm.

The results of the blade area ratio variation study for the 150-rpm propeller design are presented in Figure 6, where the dashed line represents speed and the solid line, propulsive coefficient. As expected, both speed and

the propulsive coefficient decrease linearly with increasing blade area ratio, for a fixed rpm. Increasing the blade area ratio improves the cavitation performance.

Design No. 1 of Table 3 was then run at 80-percent power to ensure that the 15-knot requirement could be met. The result, presented in Figure 7, was obtained by fixing the hydrodynamic pitch, then calculating the required thrust and propeller available thrust over a range of rpm. The 80-percent power design point is where the thrust based on available power equals the calculated thrust available from the propeller.

The propeller diameter was then varied between 12 and 14 ft. The area ratio was held constant and the thickness-chord ratio was corrected to keep the stress constant for the new chord lengths. The resulting 12-ft optimum propeller was 0.15 knot slower at a higher rpm than the 13-ft propeller. The cavitation performance was worse, and if it had been improved by adding area, the speed would have been further reduced. The 14-ft propeller design results were nearly opposite to those of the 12-ft design; however, the predicted improvements in speed (0.18 knot) and cavitation performance were not considered sufficiently better than those of the 13-ft propeller to justify allowing the propeller to protrude below the baseline of the ship.

The last parameter varied was the number of blades. The baseline propeller was again used, but with five blades rather than four, with the same blade area ratio and t/c and c/D distribution as with four blades. The results showed a 0.1-knot increase in speed, a higher propulsive coefficient (Figure 8), and a possible weight reduction at 145 rpm compared to 150 rpm of the baseline.

The basic characteristics of the designs have been presented in Table 3, along with various cavitation parameters. The diameter variation was eliminated from consideration because there was insufficient performance increase to warrant changing the diameter from 13 ft. Figure 9 shows where the propeller designs of Table 3 fall on the Burrill Diagram[6]. Designs 1 and 6, with an area ratio of 0.55, will have approximately 8-percent back cavitation at full power. The other designs show that the amount of cavitation can be reduced by increasing the blade area ratio and/or the rpm. According to Burrill's[6] work, loss of thrust begins to occur when the back cavitation exceeds 15 percent. Thus, designs 7 and 8 are eliminated from consideration because they are predicted to have back cavitation over at least

15 percent of their surface; designs 2, 3, 4, and 5 are satisfactory, but are eliminated due to a) increased cavitation at a reduced speed, and b) at reduced speed no substantial improvement to cavitation performance. These designs might be acceptable if a reduced rpm or increased speed were required. The designs for primary consideration are designs 1 and 6.

The bollard condition, for which each propeller must supply 50,000 lb of thrust, was then considered. The non-cavitating bollard thrust was approximated using the appropriate Troost open water curve to estimate, by extrapolation, the K_T and K_Q of the propeller design at $J = 0$. These parameters for all designs have been presented in Table 3. The calculated thrust and torque available, assuming no effects of cavitation, are also presented. Designs 1, 2, 4, 5, and 6 can provide the required thrust without exceeding the torque limit of 260,000 ft-lbs. The torque limit is slightly exceeded by design 3 at full power.

The thrust and torque values presented in Table 3 do not account for the effects of cavitation. Therefore, a check must be made for cavitation, as was done for the free-running condition, to ensure that thrust breakdown will not occur at the bollard conditions of 50,000-lb thrust and full power.

Enkvist and Johanson[7] have compiled data on numerous propellers operating in the bollard condition and have developed a boundary for occurrence of thrust breakdown. The results of this prediction were reduced for comparison with the propeller of this design and are presented in Figure 10. The three designs (1, 6, and the final) presented here are for the full-power condition. It can be seen that no thrust breakdown (loss of thrust) should occur. The actual values of the plotted points are provided in Table 3. Though not presented here, Prishchemikhin[8,9] also gives data on thrust breakdown in the bollard condition. His results were extrapolated and showed that there was little chance of thrust breakdown occurring. Therefore, the previously chosen designs, designs 1 and 6 of Table 3, will meet the specified propulsion requirements.

Designs 1 and 6 were then modified to include 30 degrees of linear skew and an increased area ratio to reduce the high level of unsteady force which, as determined by reference 10, resulted from the high shaft angle, the shaft housing, and centerline skeg. The results of an overall vibration analysis conducted by DTNSRDC Code 1962 favored the four-bladed skewed design over the five-bladed skewed design because of the rpm for longitudinal

resonance relative to the design propeller rpm. The longitudinal resonance occurred at 192 rpm for the four-bladed design and at 156 rpm for the five-bladed design which also required additional machinery stiffening.* The final design was therefore the four-bladed propeller with a blade area ratio of 0.78 operating at 145 rpm.

RESULTING GEOMETRY

The final lifting-line calculations were performed for the full-power condition using the final value of all the pertinent design parameters. This computation shows that the total absorbed power, $P_{D_{FP}}$, at V = 15.95 knots is 10,000 hp (7,457 kW) for the two propellers. The endurance power, P_{D_E}, was specified to be 0.80 times full power, P_D; thus, P_{D_E} = 8,000 hp (5,966 kW).

Lifting-line computations were also performed for the endurance condition assuming that the distribution, but not the total magnitude, of the loading at endurance power is the same as it is at the full-power condition (see Tables 4 and 5). This is a reasonable assumption because the advance coefficient changes minutely between the full-power and endurance conditions, assuming that the interaction coefficients are the same as obtained in the model experiments of Reference 2 with stock propellers. Computations based on the above assumptions indicate that V = 14.9 knots will be obtained at endurance power.

The model pitch and camber distributions were determined using the lifting-surface procedure of Kerwin[11] (see Table 6) and are compared in Figures 11 and 12 to the lifting-line values of pitch and two-dimensional camber. These computations were made for the full-power condition. The model propeller characteristics are presented in Table 4; a schematic drawing of the propeller is presented in Figure 13.

STRENGTH CALCULATIONS

The final stress analysis of the propeller blades was made using finite element procedures. Stresses calculated by finite element methods are considered more accurate than stresses calculated by modified beam theory as in

*Defined informally by memorandum from Code 6144R, Ser 134, Res 1970. Subject "T-ARC, Propeller Design Status Report Based on Propulsion System Vibration Analysis."

Reference 4. The finite element calculations were conducted for the time-average loading on the blade at the full-power condition. The radial distribution of hydrodynamic loading was calculated by lifting-line theory (see Table 5), and the centrifugal loading was calculated during the finite element computations, using uniform chordwise load distribution.

Figure 14 presents the distribution of time-averaged stresses calculated by the finite element procedure. The maximum value of the Hencky-Von Mises Stress, $\bar{\sigma}_{HVM}$, for this propeller is 2,720 psi (18.76 MPa) and occurs, at mid-chord, on the face of the blade at r/R = 0.30. This is substantially less than the maximum stress calculated by the modified beam theory (σ_p = 6,692 psi) (42.12 MPa). The low values of stress are probably due to the abnormally large thickness introduced for ice strengthening, and are far below the maximum allowable principal stress of 12,500 psi for the steady condition and 18,750 psi based on the unsteady condition. Thus, the blade stresses are acceptable.

COMPARISON OF DESIGN AND EXPERIMENTAL PERFORMANCE PREDICTIONS

Hydronautics, Inc. Model 7809-9, modified to conform with References 12 and 13, was fitted with DTNSRDC model Propellers 4761 and 4762. The hull modifications and the experimental results are reported in Reference 3. A summary of the experimental data is given in Table 7. Those modifications, which would influence the propeller design and which change the model from that used for the original propulsion tests of Reference 2, are:

1. Increasing the diameter of the exposed shaft to equal the diameter of the strut barrel and hull bossing.
2. Thinning and lengthening the skeg.
3. Fairing the stern transom/underbody intersection.
4. Decreasing the inside diameter of the thruster openings.
5. Increasing the rudder area by increasing the chord length at the top.

These modifications reasonably account for the 6.4 and 5.1 percent reduction in P_E and $(1-w_T)$, respectively and the 4.1 percent increase in (1-t), shown in Table 7, columns 1 and 2.

The lifting-line code was used with the final estimation of EHP, $(1-w_T)$, and (1-t) from Reference 3 to revise the full-scale performance predictions of the designed propeller, and for comparison to the model test

results. These calculations were done by fixing the shape and magnitude of the hydrodynamic pitch, then calculating the required thrust and propeller available thrust (for fixed power) over a range of rpm's for fixed (1-t) and P_E variable with speed. The rpm at which the two thrust values are equal is approximately the operating point. (These calculations are similar to the design computations previously shown in Figure 7.) The results of these calculations, presented in Table 7 (columns 3 and 4), predict an increase in speed of 0.68 knots, an increase in propulsive efficiency of 0.05, and a reduction of 1 rpm for the existing design, operating at full-scale conditions relative to the design predictions.

Correlation of predictions and the model test results requires that the performance prediction calculations be made using blade drag coefficients, which account for the large difference in Reynolds Number between model tests and full scale. This effect is not accounted for in full-scale predictions using experimental data. In this case, the model blade drag coefficient at 0.7R is 0.011 compared to 0.005 for full-scale operation. Calculations made, as above, using the model blade drag coefficient show reductions in speed of 0.3 knots, a reduction in rpm of 3, and a reduction in propulsive efficiency of 0.05 relative to design predictions (comparing columns 4 and 5 in Table 7). Comparing these results (column 5) with the final model test results (column 2) shows the predicted speed 2.2 percent less at practically the same rpm, and the propulsive efficiency reduced by 7 percent.

Considering the large change in P_E, $(1-w_T)$, and (1-t), and assuming the scale effect on the propeller wake is negligible, the predicted performance is in acceptable agreement with the experimental results.

SUMMARY

The design process was presented for a fixed-pitch propeller of a Cable-Laying Repair Ship (T-ARC). The primary requirement was to provide a minimum of 50,000 pounds thrust per propeller at bollard (and low speed) to overcome the cable drag. A simple sensitivity study was done on the various design parameters.

The resulting propeller design is 13.00 feet (3.963 m) in diameter and turns at 145 rpm at full power and 135 rpm at endurance power. Calculations indicated that this propeller will perform satisfactorily, but that there will be about 2-percent cavitation at full power, and if the

included 6-percent margin is required, endurance speed for 15 knots may not be attainable at 80- percent power. However, the required thrust at low speed will be attainable.

Comparison of lifting-line predictions, revised by the results of Reference 3 and the experimental results show the lifting-line predictions to be reduced in speed by 0.3 knots and increased by 1 rpm, and the propulsive efficiency to be reduced by 0.05. These results are considered acceptable, taking into account the large changes in P_E, $(1-w_T)$, and $(1-t)$ due to hull modifications and the use of the design propellers rather than stock propellers.

Prior to full-scale construction, it was found that the shaft diameter and propeller blade thickness did not meet the design specifications. The new shaft diameter and proper ABS thickness rules were then used to recalculate the blade thickness. Details of the change are given in Appendix A. An example of this change is that the thickness was increased by 0.5 inch at the mid-chord of the 0.7 radius. The thickness increase results in an insignificant reduction in ship speed and η_D at the endurance condition of 0.003 knot and 0.005, respectively. There will be no effect on the cable-laying operations.

RECOMMENDATIONS

It is recommended that trials be conducted to evaluate performance, considering propulsion, cavitation, strength and propeller-induced vibration as compared to the lifting-line and experimentally predicted performance. Due to the large changes in hull performance, it is recommended that a wake survey be conducted on the final hull configuration and that the propeller design be evaluated with respect to these new data.

Recommendations with respect to the design procedures include the following:

1. Better methods are needed for predicting changes in P_E, (1-t), and $(1-w_T)$ due to hull and appendage changes, or additional tests should be conducted. Using two stock propellers during propulsion tests would be advantageous with regard to potential changes in (1-t) and $(1-w_T)$ due to propeller-induced velocities.
2. Improvement is needed in the prediction of the required power and the prediction of propeller blade drag coefficient for both model and full-scale.
3. Cavitation tests in the bollard condition should be conducted to expand the limited data base in this area for future designs.

REFERENCES

1. Wendel, A.H. and Poquette, G.M., "Initial Propeller Performance Calculations for T-ARC," Hydronautics, Inc., Technical Report TR 7809.02-1, Sep. 1977.

2. Kirkman, K. et al, "Cable Repair Ship (T-ARC) Contract Design Resistance and Powering and Related Tests," NAVSEC Report 6136-78-28, Oct. 1978.

3. Ternes, T., "Cable Repair Ship (T-ARC-7) Revised Contract Design Resistance and Design Propeller Powering Tests," NAVSEA Report 3213-79-33, Nov. 1979.

4. Eckhardt, M.K., and Morgan, W.B., "A Propeller Design Method," Trans. SNAME, Vol. 63, pp. 325-374, 1955.

5. Caster, E.B. et al, "A Lifting Line Computer Program for Preliminary Design of Propellers," DTNSRDC Report SPD-595-01, Nov. 1975.

6. Burrill, L.C. and Emerson, A., "Propeller Cavitation: Further Tests on 16-Inch Propeller Models in the King's College Cavitation Tunnel," NECI, 1962-1963.

7. Enkvist, E. and Johanson, B.M., "On Icebreaker Screw Design," European Shipbuilding No. 1, pp. 2-14 and 18-19, 1968.

8. Prishchemikhin, J.N., "Some New Experimental Data on Cavitating Propellers and the Interaction Between These and the Hull," Proceedings of 12th ITTC, Rome, 1969.

9. Prishchemikhin, J.N., "A Study of the Cavitating Propeller and Ship Hull Interaction in Cavitation Towing Tank," Proceedings of 14th ITTC, 1975.

10. Breslin, J.P., "Theoretical and Experimental Techniques for Practical Estimation of Propeller-Induced Vibratory Forces," Trans. SNAME, Vol. 78, pp. 23-40, 1970.

11. Kerwin, J.E., "Computer Techniques for Propeller Blade Section Design," Proceedings, Second Lips Propeller Symposium, Drunen, Holland, pp. 7-31, May 1973.

12. Naval Sea Systems Command Drawing No. 5171279, "Cable Repair Ship T-ARC Lines and Molded Offsets."

13. Naval Sea Systems Command Drawing No. 5171290, "Cable Repair Ship (T-ARC) Contract Design Rudder and Appendages."

APPENDIX A
MODEL AND FULL-SCALE GEOMETRY DIFFERENCES

The specifications of the T-ARC model and the full-scale propeller geometry are slightly different. The difference between the propellers is the maximum section thickness. Prior to full-scale construction, it was determined by ABS inspection that the propeller did not meet the thickness requirement of Class C ice strengthening and that the propeller shaft did not meet the required ABS diameter.

The propeller thickness was not acceptable because the most recent of the ice strengthening rules had not been incorporated. Instead, the rules for a previous year had been applied. In addition, the shaft was undersized because the ABS rules for standard shaft arrangements were followed rather than those for enclosed shafting and oil lubricated strut bearings. Each item independently would have required recalculation of the propeller thickness. These deficiencies were not appreciated during the initial design process because the propeller thickness distribution and shaft diameter were already quite sizeable by conventional standards.

The use of the proper thickness equations as well as the new shaft diameter produced an increase in the maximum blade-section thickness values (e.g., 0.5 inch at the 0.7 radius). The resulting change in predicted performance is insignificant, as can be seen by comparison of the revised lifting-line calculations for both the full-power and endurance conditions, Tables 8 and 9, respectively, with Tables 4 and 5 in the text. The revised lifting surface computation is presented in Table 10 for comparison with Table 6 in the text.

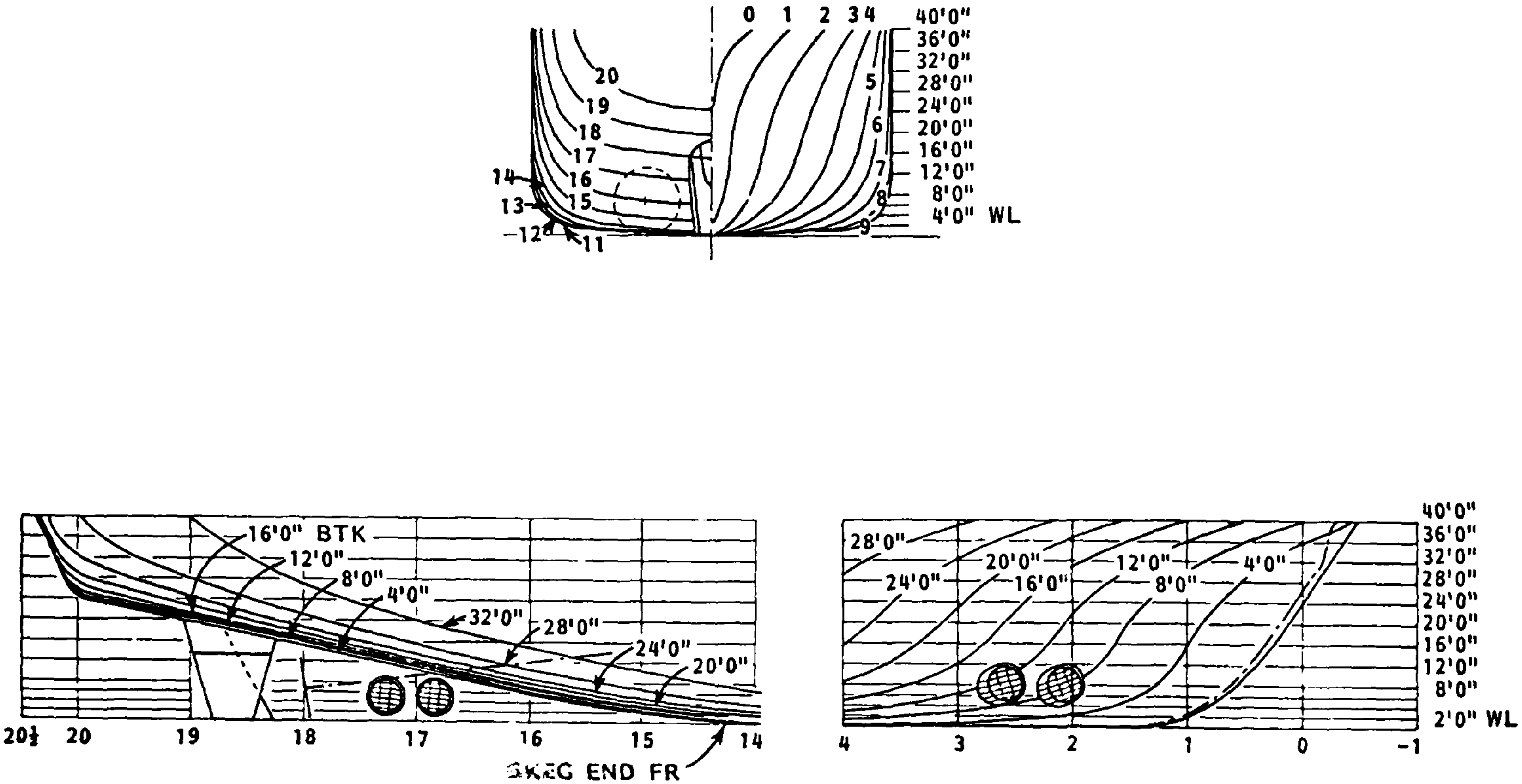


Figure 1 - Body Plan and Bow and Stern Profiles of Revised T-ARC Contract Design (Fig. 1 of Ref. 2)

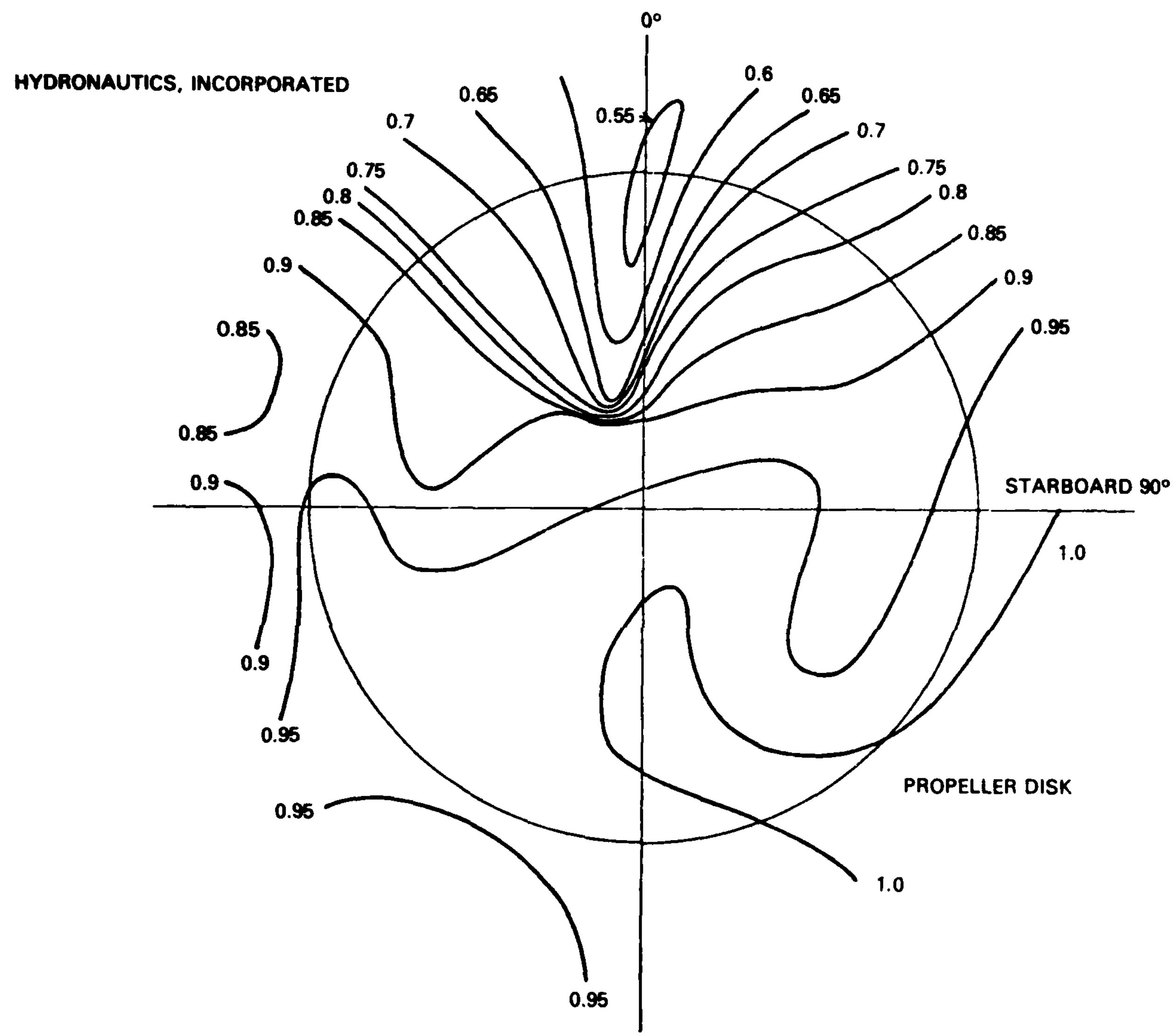


Figure 2 - Contour Map of the Longitudinal Velocity Components in the Starboard Propeller Plane of HSMB Model 7809-2 (Fig. 3 of Ref. 1)

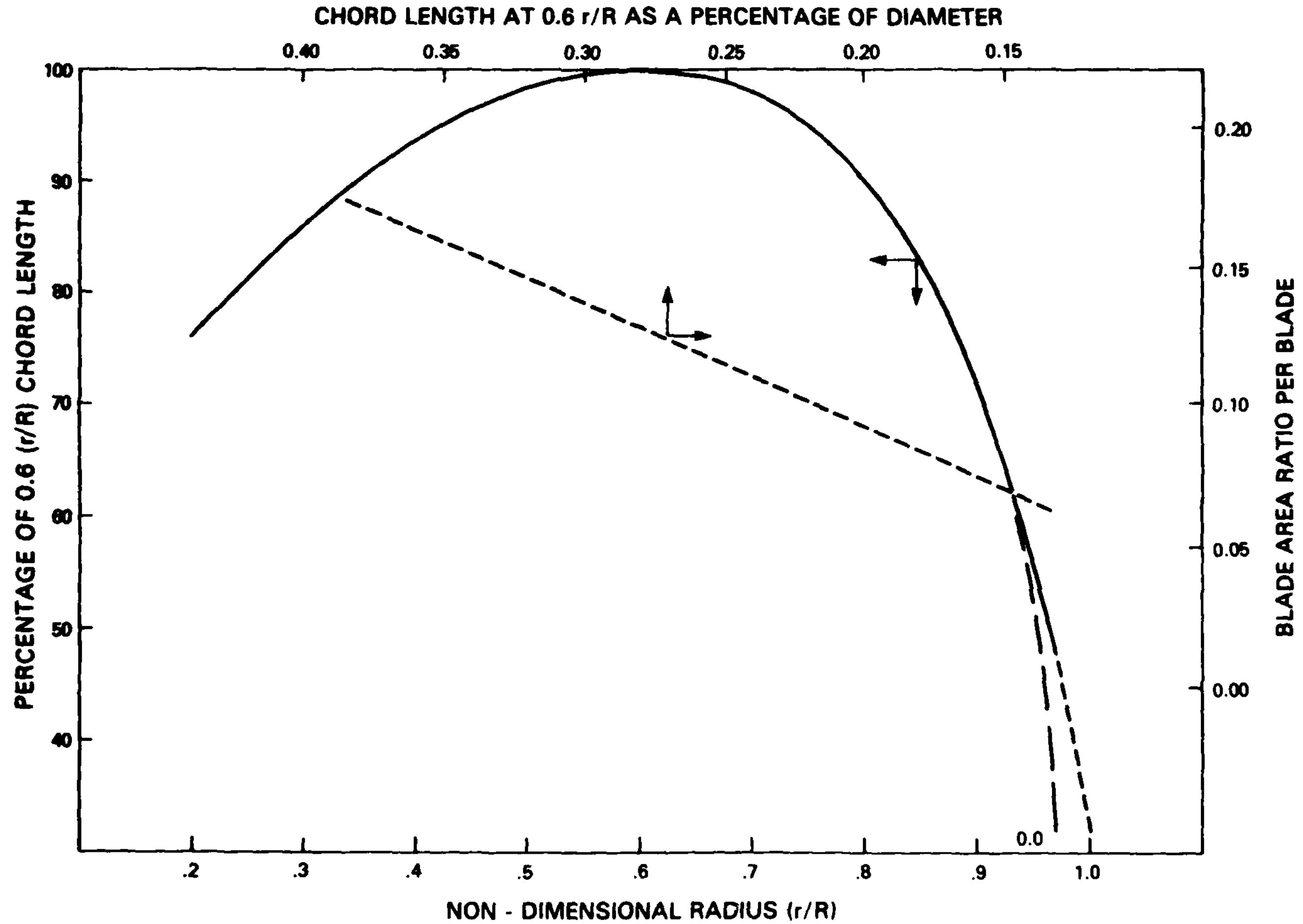


Figure 3 - Chord-Diameter Ratio Distribution as a Function of Radius and Blade Area Ratio for the Troost Series Propellers

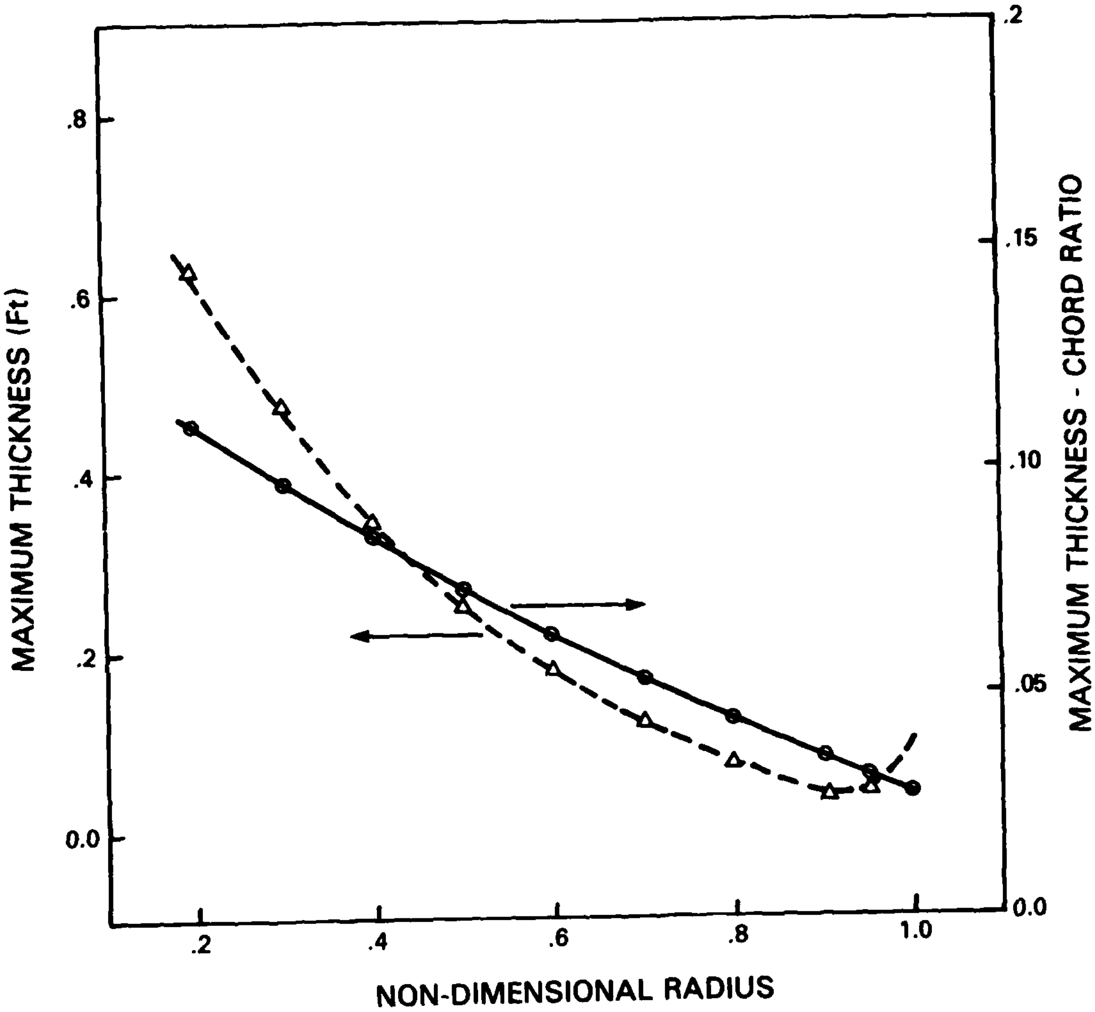


Figure 4 - Initial Thickness-Chord Ratio Distribution

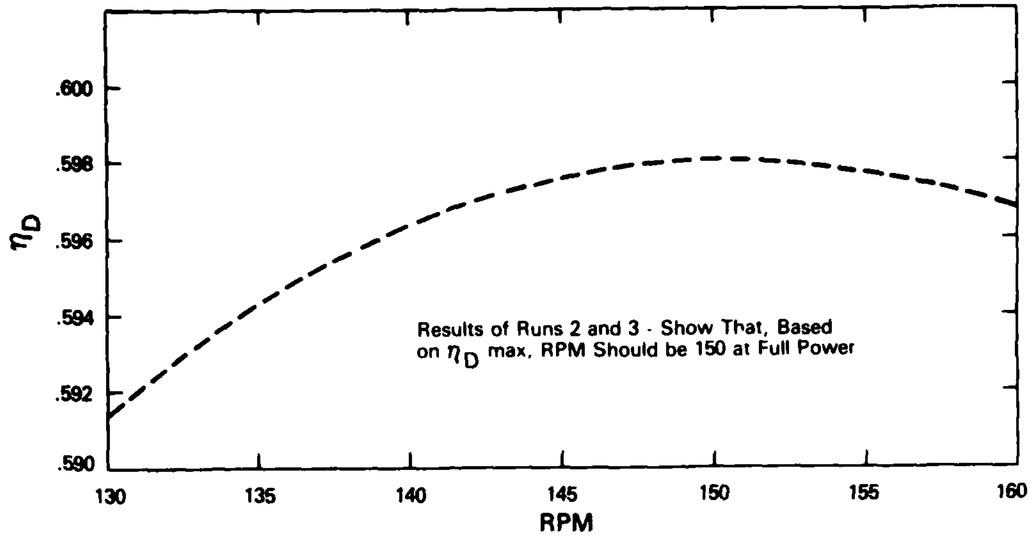


Figure 5 - Propulsive Coefficient as a Function of RPM for the Preliminary Design

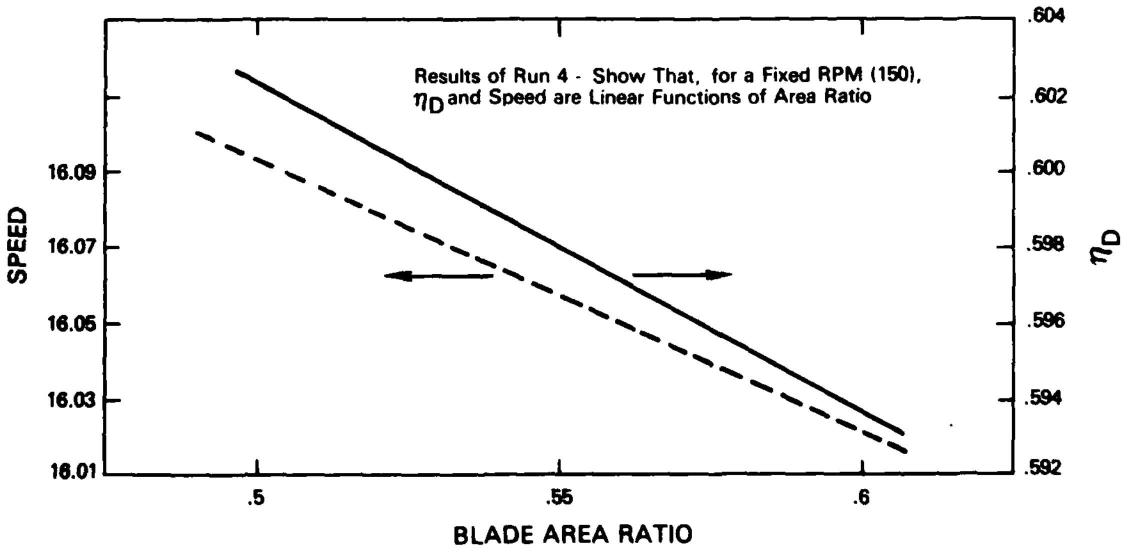


Figure 6 - Propulsive Coefficient and Ship Speed as a Function of Blade Area Ratio

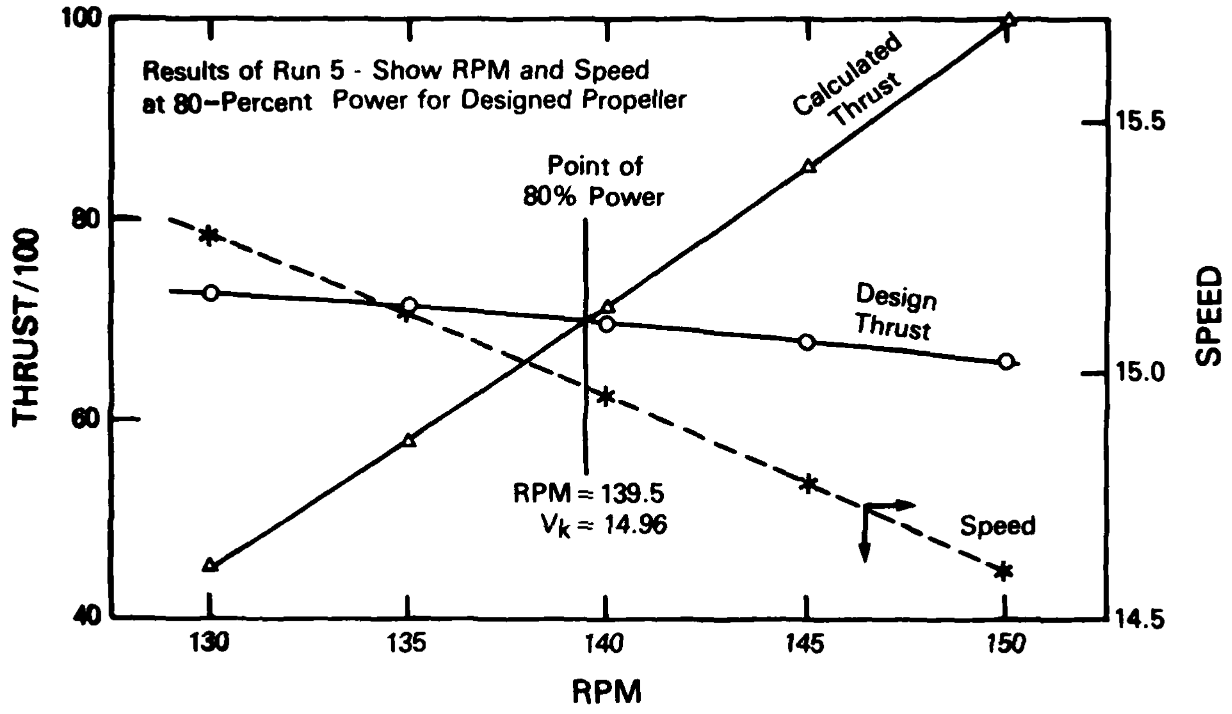


Figure 7 - Cross Plot of Available and Required Thrust to Determine the 80-Percent Power, Ship Speed, and RPM

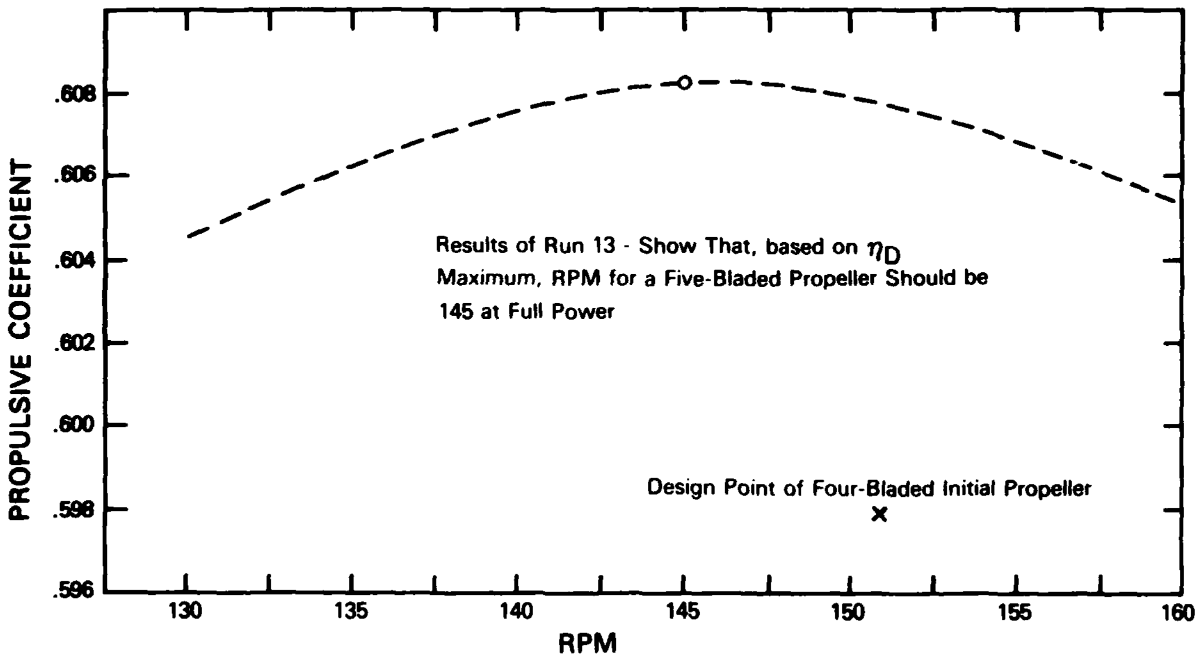


Figure 8 - Propulsive Coefficient as a Function of RPM for a Five-Bladed Propeller with the Preliminary Design Characteristics

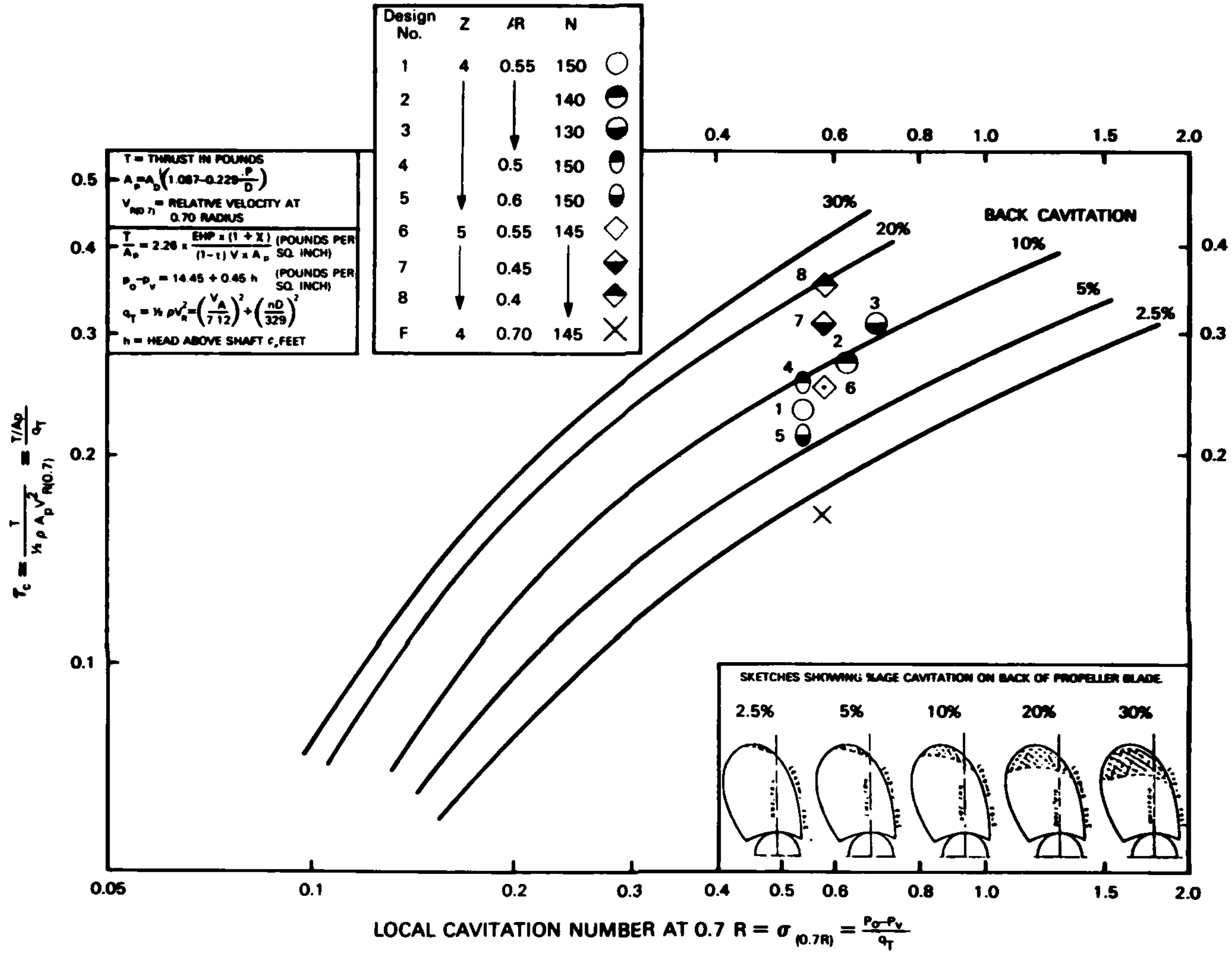


Figure 9 - Cavitation Performance of Propeller Designs at Full Power with Respect to the Burrill Diagram

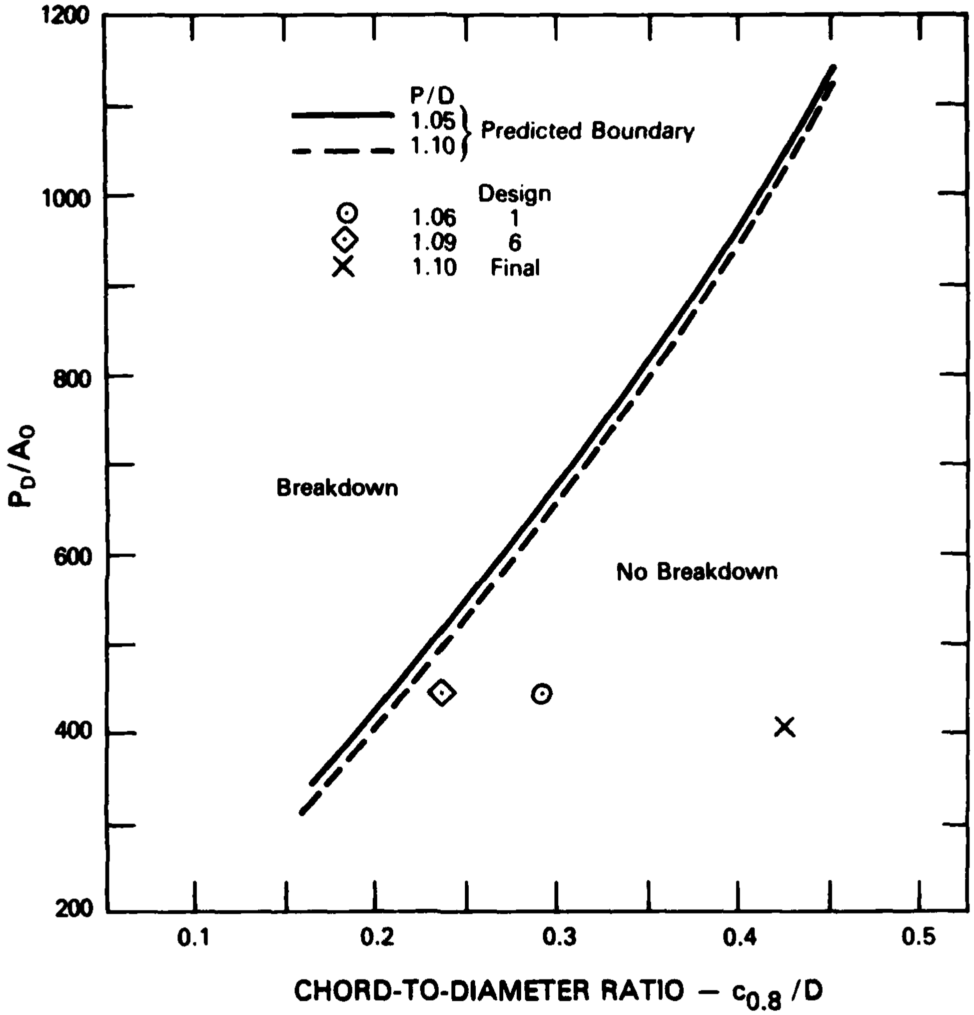


Figure 10 - Thrust Breakdown at Bollard Condition

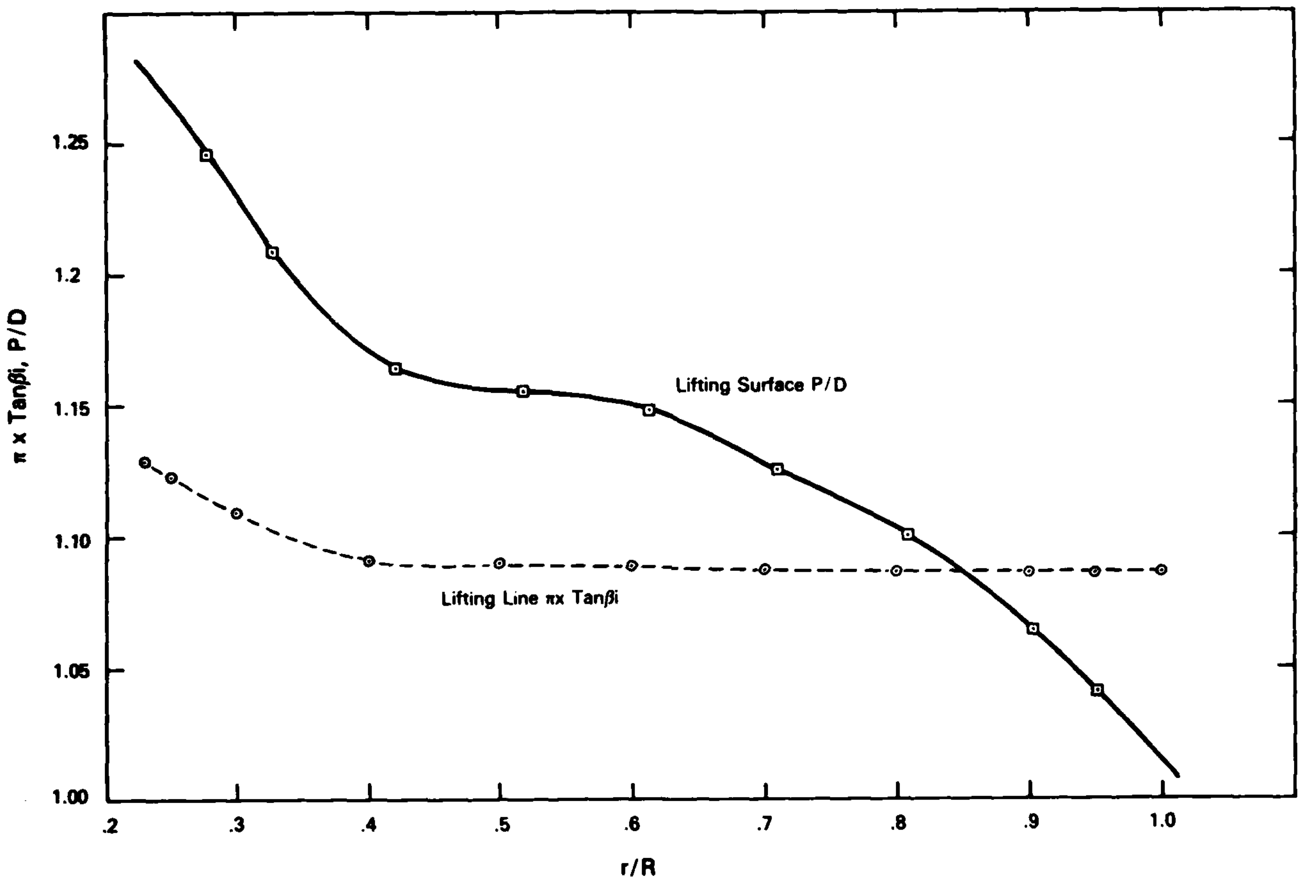


Figure 11 - Hydrodynamic Pitch Distribution from Lifting Surface Calculations Compared with Lifting Line Calculations

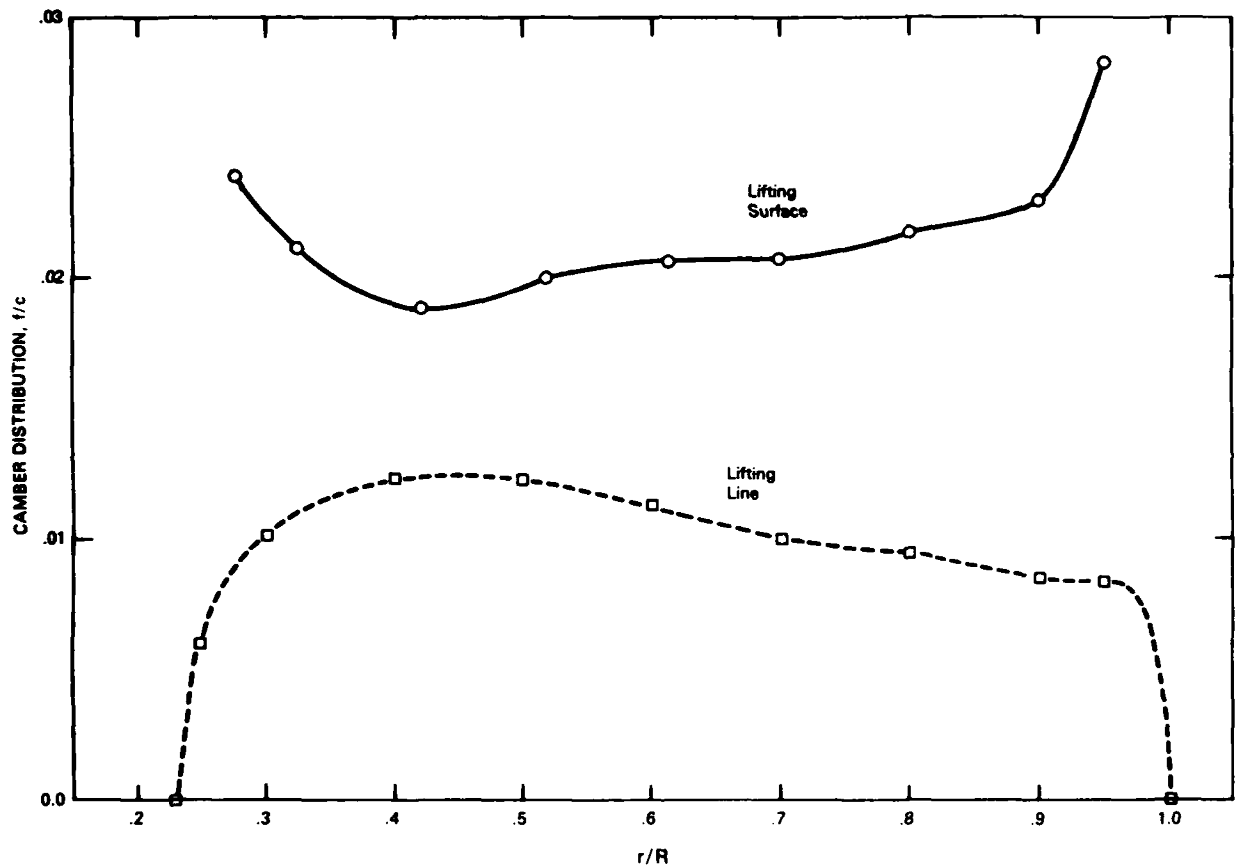


Figure 12 - Final Camber Distributions from Lifting Surface Calculations Compared with Lifting Line Calculations

	Prop. Number	Linear Ratio	Dia. Model	Dia. Ship	Pitch Model at 70 PCT.	Pitch Ship at 70 PCT.	Pitch Ratio at 70 PCT.	Number of Blades	EXP. Area	E.A./D.A.	M.W.R.	Proj. Area	P.A./D.A.	B.T.F.	Rake Angle at Tip	Rotation	Ship Model	Section Length Model at 70 PCT.
Inches MM	4761	19.500	8.000 203.20	156.000 3962.40	9.244 234.79	180.250 4578.35	1.155	4.	39.706 25615.8	0.790	0.395	31.608 20391.9	0.629	0.041	0.000	R.H.		3.697 93.91
Inches MM	4762	19.500	8.000 203.20	156.000 3962.40	9.244 234.79	180.250 4578.35	1.155	4.	39.706 25615.8	0.790	0.395	31.608 20391.9	0.629	0.041	0.000	L.H.		3.697 93.91

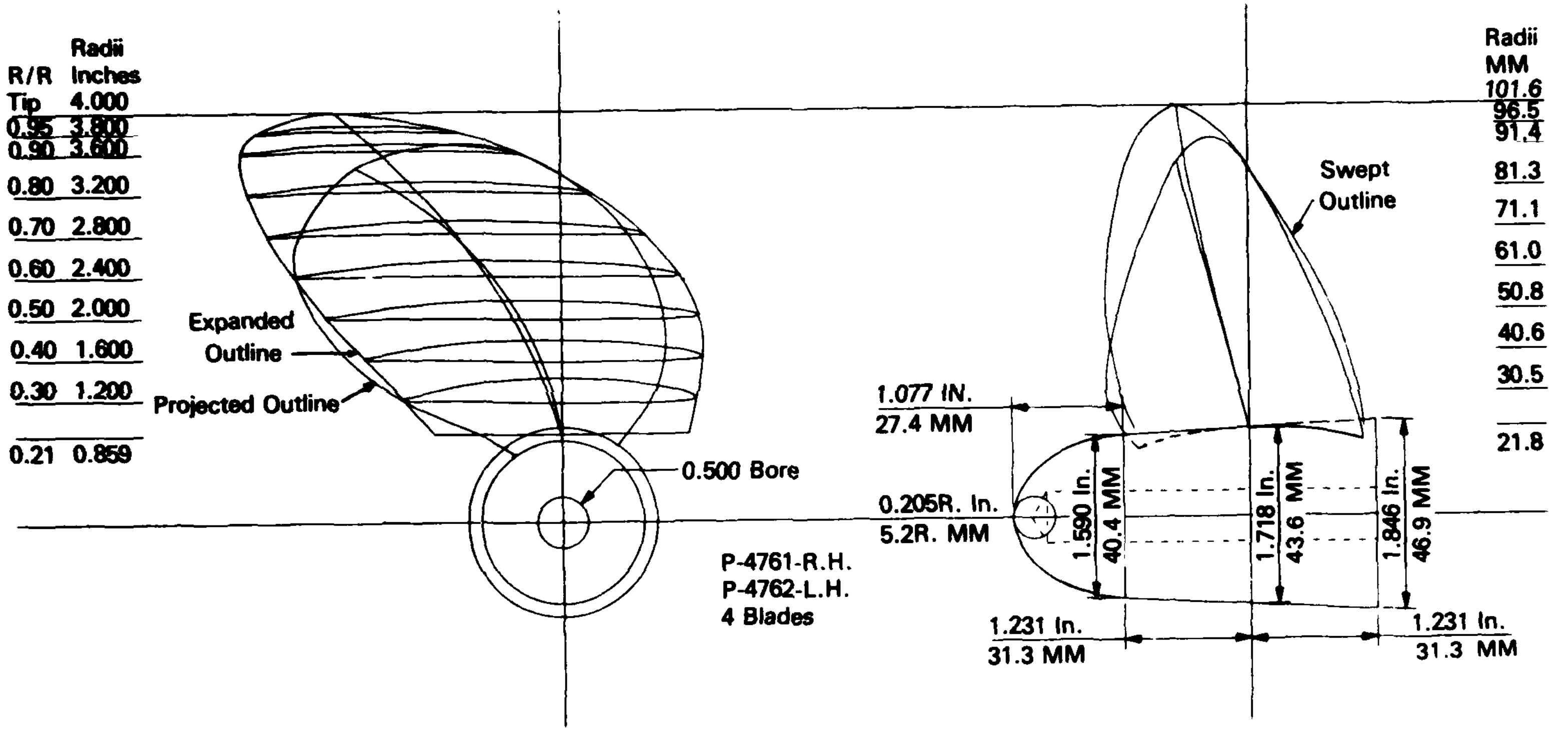
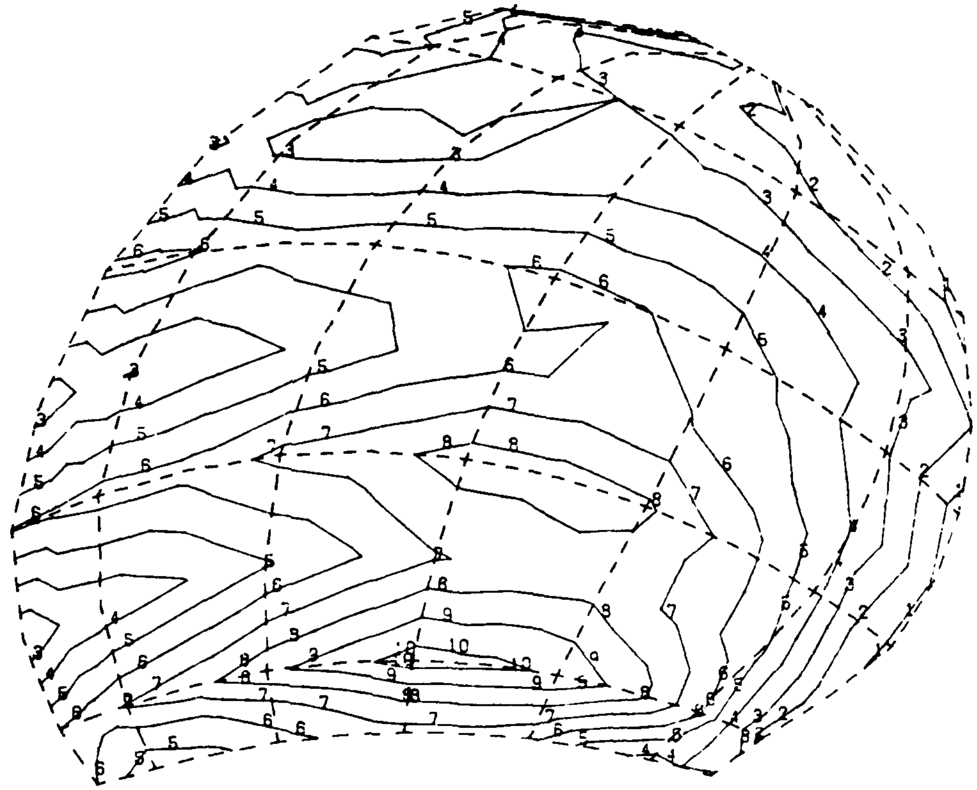


Figure 13 - Schematic Drawing of Final Propeller Design

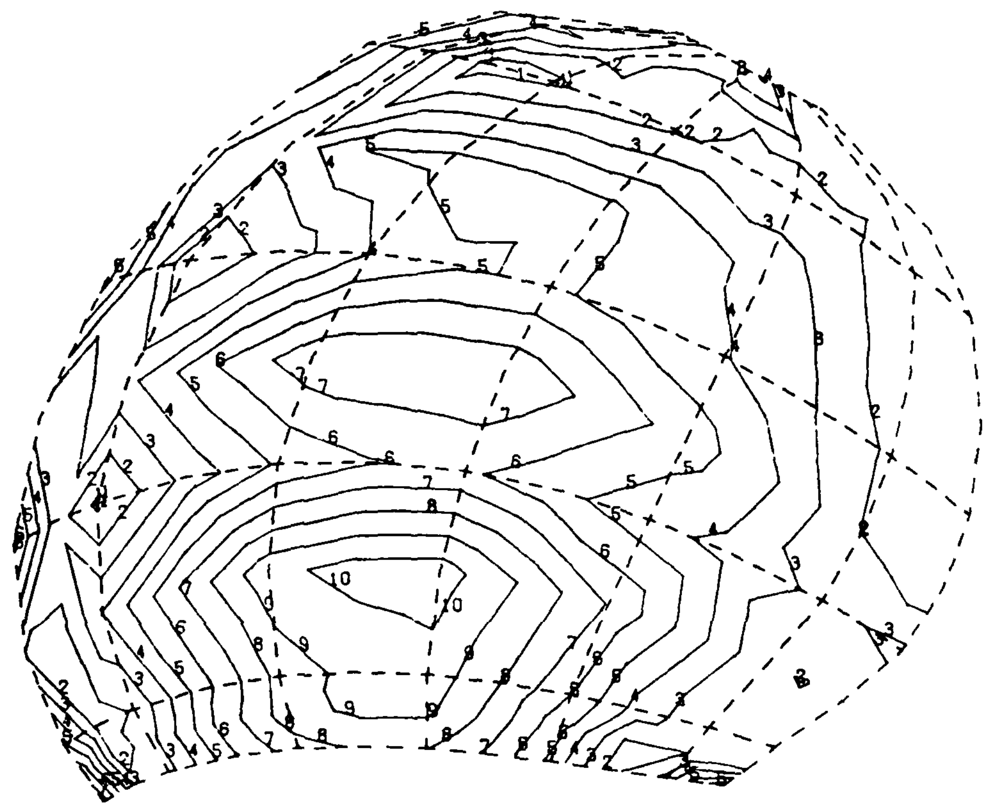
Number	Hencky-Von Mises Stress, σ_{HVM} (PSI)
1	122
2	411
3	700
4	989
5	1280
6	1570
7	1860
8	2150
9	2430
10	2720

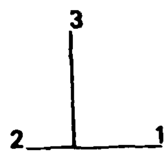


PROPELLER 4763 VON MISES STRESS FACE

Figure 14 - Results of Finite Elements Stress Analysis

Number	Hencky-Von Mises Stress, σ_{HVM} (PSI)
1	155
2	382
3	609
4	832
5	1060
6	1290
7	1520
8	1740
9	1970
10	2200





PROPELLER 4763 VON MISES STRESS BACK

Figure 14 - (Continued)

TABLE 1 - SHIP AND MODEL PARTICULARS FOR REVISED T-ARC CABLE REPAIR SHIP CONTRACT DESIGN

	DIMENSIONS			
	Full Load		Light Condition (No Cable Load)	
	Ship	Model	Ship	Model
Length, LWL	464.0 ft (141.4m)	23.79 ft (7.25m)	442.0 ft (134.7m)	22.67 ft (6.91m)
Length, LBP	464.0 ft (141.4m)	23.79 ft (7.25m)	464.0 ft (141.4m)	23.79 ft (7.25m)
Beam at AX (MLD)	73.0 ft (22.3m)	3.74 ft (1.14m)	73.0 ft (22.3m)	3.74 ft (1.14m)
Draft at AX (MLD)				
Fwd	23.72 ft (7.23m)	1.22 ft (0.37m)	19.11 ft (5.82m)	0.98 ft (0.30m)
Aft	24.10 ft (7.35m)	1.24 ft (0.38m)	20.39 ft (6.21m)	1.05 ft (0.32m)
Displacement	499985.0 ft^3(14159.0m^3)	67.43 ft^3(1.91m^3)	390319.0 ft^3(11053.0m^3)	52.64 ft^3(1.49m^3)
Wetted Surface	43117.0 ft^2(4006.0m^2)	113.4 ft^2(10.54m^2)	38424.0 ft^2(3569.8m^2)	101.0 ft^2(9.39m^2)
Trim (by stern)	0.38 ft (0.12m)	0.02 ft (0.006m)	1.28 ft (0.39m)	0.066 ft (0.02m)
	Coefficients			
C_B	0.617		0.613	
C_P	0.650		0.660	
C_x	0.941		0.929	
L/B_x	6.356		6.356	
Propeller Diameters (twin screw)	13.0 ft (3.96m)	0.667 ft (0.203m)		
Linear Scale Ratio	1	19.5		

TABLE 2 - FINAL RESISTANCE DATA FOR T-ARC DERIVED FROM HSMB MODEL TESTS AND NAVSEA CALCULATION (10/16/78)

Ship Speed, V		Effective Power, P_E with Air Drag and 6% Margin	
knots	m/s	hp	kW
6	3.09	284	212
7	3.60	448	334
8	4.12	668	498
9	4.63	942	702
10	5.14	1303	972
11	5.66	1794	1338
12	6.17	2404	1793
13	6.69	3133	2336
14	7.20	3994	2978
15	7.72	4931	3677
16	8.23	6075	4530
17	8.75	7582	5654

Note 1: These effective power values are 7.14% lower than the initial values provided.

Note 2: New estimates for the following were also provided.

$1 - t = 0.830$

$1 - w_T = 0.970$

TABLE 3 - DESIGN PARAMETERS AND RESULTS FOR A 13-FT DIAMETER PROPELLER FOR THE VARIOUS DESIGN REQUIREMENTS

			1	2	3	4	5	6	7	8	Final
DESIGN PARAMETERS (T and Q are for one propeller)		Design No.	1	2	3	4	5	6	7	8	Final
		Z	4	4	4	4	4	5	5	5	4
		EAR	0.55	0.55	0.55	0.50	0.60	0.55	0.45	0.40	0.78
		RPM	150	140	130	150	150	145	145	145	145
		V	16.059	16.045	16.004	16.093	16.022	16.142	16.200	16.228	15.947
		T	81,071	80,935	80,474	81,469	80,673	82,017	82,668	82,981	73,983
BOLLARD CONDITION	To Provide 5000 lbs Thrust/Shaft	n	80.9	77.7	74.9	80.9	-	78.0	-	-	78.8
		Q	106,414	116,505	128,991	106,414	-	112,410	-	-	107,080
		SHP	1,639	1,724	1,840	1,639	-	1,669	-	-	1,607
	Full-Power Condition	n	121.1	114.4	107.9	121.1	-	116.0	-	-	115.0
		T	112,090	108,297	103,694	112,090	-	110,050	-	-	106,603
		Q	238,535	252,505	267,717	238,535	-	248,888	-	-	228,255
		SHP	5,500	5,500	5,500	5,500	-	5,500	-	-	5,000
BURRILL CAVITATION PARAMETERS	Design Values (Free Running ar Full Power)	J	0.781	0.836	0.898	0.782	0.779	0.812	0.815	0.816	0.831
		K_T	0.228	0.262	0.302	0.229	0.227	0.247	0.249	0.250	0.223
		K_Q	0.0417	0.0513	0.0640	0.0417	0.0461	0.0461	0.0461	0.0461	0.0420
		τ_c	0.236	0.273	0.319	0.262	0.215	0.256	0.315	0.355	0.163
		$\sigma_{0.7}$	0.555	0.627	0.714	0.555	0.555	0.589	0.588	0.588	0.585
	Estimated for J = 0	K_T	0.484	0.524	0.564	0.484	0.484	0.520	0.520	0.520	0.510
		K_Q	0.0792	0.0940	0.1120	0.0792	0.0792	0.0900	0.0900	0.0900	0.0840
	Bollard Conditions	τ_c	0.561	-	-	-	-	0.611	-	-	0.422
		$\sigma_{0.7}$	2.16	-	-	-	-	2.32	-	-	2.27
	Full Power	τ_c	0.560	-	-	-	0.603	-	-	-	0.422
		$\sigma_{0.7}$	0.96	-	-	-	1.05	-	-	-	1.07
Data Used for Figure 10		$c_{0.8R}/D$	0.292	-	-	-	0.234	-	-	-	0.425
		P/D	1.06	-	-	-	1.09	-	-	-	1.07
		P_D/A_0	446	-	-	-	446	-	-	-	405

TABLE 3 (Continued)

Equations and Calculations used for Table 3

(1) RPM Required to Provide 50,000 pound Thrust at Bollard Condition (J = 0)

$$n = (T/\rho D^4 K_T)^{1/2} \cdot (60)$$

(2) Torque at 50,000 pound Thrust at J = 0

$$Q = K_Q \, \rho D^5 n^2$$

(3) Shaft Horsepower at 50,000 pound Thrust at J = 0

$$SHP = 2\pi Qn/550$$

(4) RPM at Bollard for Full Power

$$n = (550 \cdot SHP/2\pi\rho D^5 K_Q)^{1/3} \cdot (60)$$

(5) Thrust at Bollard for Full Power

$$T = K_T \rho n^2 D^4$$

(6) Torque at Bollard for Full Power

$$Q = 550 \cdot SHP/2\pi n$$

TABLE 4 - LIFTING-LINE CALCULATIONS AT FULL-POWER CONDITION

T-ARC OUTBOARD TURNING PROP **** FINAL DESIGN ****

P_D (HP) = [illegible]E+03, DENSITY OF PROP(LBM/FT3)= 468.2930

V (KNOTS) = 1.3000E+01 1.4000E+01 1.5000E+01 1.6000E+01 1.7000E+01
PE (HP) = 1.5665E+03 1.9978E+03 2.4655E+03 3.0375E+03 3.7910E+03
Z = [illegible]
A_E/A_0 = 7.7589E-01
N (RPM) = 1.3300E+02 1.3460E+02 1.3580E+02 1.3600E+02
D = 13.0000 ,1 - W_T=.9700 ,1 - t=.8300 ,H(FT)= 49.4100 ,ρ (SLUG/FT³) = 1.9906

X INPUT	$1 - W_X$ INPUT	c/D INPUT	t/c INPUT	$\tan \beta_i$ (PREL)	$\tan \beta$ CALCULATED	θ_e (deg)	Z_R	$x \tan \beta_i$	C_D INPUT
.231	[illegible]	3.1790E-01	1.0396E-01	1.6674E+00	1.2927E+00	-5.6843E-14	0.	1.1665E+00	6.6800E-03
.250	1.0285E+00	3.3068E-01	9.7730E-02	1.4469E+00	1.1336E+00	7.4122E-01	0.	1.1364E+00	6.5600E-03
.300	1.0199E+00	3.5860E-01	8.6980E-02	1.2807E+00	9.3664E-01	2.6918E+00	0.	1.1316E+00	6.2400E-03
.400	[illegible]	4.1330E-01	6.6460E-02	[illegible]	6.8600E-01	6.5936E+00	0.	1.1193E+00	5.7700E-03
.500	9.7998E-01	4.5610E-01	5.0730E-02	7.6616E-01	5.3399E-01	1.0494E+01	0.	1.1092E+00	5.4400E-03
.600	[illegible]	4.7180E-01	4.1630E-02	5.8657E-01	[illegible]	1.6395E+01	0.	1.1019E+00	5.2300E-03
.700	9.5947E-01	4.6206E-01	3.4700E-02	4.9909E-01	3.7763E-01	1.8296E+01	0.	1.0976E+00	5.0900E-03
.800	[illegible]	4.2466E-01	2.8600E-02	4.3695E-01	3.3340E-01	2.2198E+01	0.	1.0982E+00	5.0300E-03
.900	[illegible]	3.4136E-01	2.5200E-02	3.8797E-01	2.9334E-01	2.6099E+01	0.	1.0970E+00	5.1000E-03
.950	9.5731E-01	2.4659E-01	2.7300E-02	3.6734E-01	2.7763E-01	2.8349E+01	0.	1.0963E+00	5.3400E-03
1.000	[illegible]	0.	2.9460E-02	3.4878E-01	2.6345E-01	3.0000E+01	0.	1.0957E+00	5.5000E-03

X	$\tan \beta_i$	$\tan \beta$	G	U_T/V	U_A/V	$d(C_{ThSI})$	$d(C_{psI})$	V_r	σ
.231	[illegible]	1.2830E+00	0.	1.2266E-01	7.6923E-02	0.	0.	3.4350E+01	7.6132E+00
.250	[illegible]	1.1249E+00	9.8068E-03	1.3646E-01	9.6427E-02	1.1209E-01	1.4828E-01	3.4375E+01	7.6029E+00
.300	[illegible]	9.2968E-01	1.7293E-02	1.4412E-01	1.2439E-01	2.6369E-01	3.4737E-01	3.7418E+01	2.1898E+00
.400	[illegible]	6.8172E-01	2.6951E-02	1.5034E-01	1.7173E-01	5.6610E-01	7.3748E-01	4.4169E+01	1.5469E+00
.500	[illegible]	5.3593E-01	3.3017E-02	1.4573E-01	[illegible]	8.0900E-01	1.1479E+00	5.1764E+01	1.1091E+00
.600	5.8657E-01	4.4071E-01	3.6529E-02	1.3716E-01	2.3551E-01	1.2217E+00	1.5416E+00	5.9873E+01	8.1676E-01
.700	[illegible]	3.7480E-01	3.7502E-02	1.2707E-01	2.5477E-01	1.4598E+00	1.8651E+00	6.8322E+01	6.1808E-01
.800	4.3695E-01	3.2832E-01	3.5415E-02	1.1647E-01	2.6636E-01	1.5918E+00	2.0349E+00	7.7031E+01	4.7919E-01
.900	3.8797E-01	2.9118E-01	2.8530E-02	1.0734E-01	2.7693E-01	1.4538E+00	1.8564E+00	8.5816E+01	3.8042E-01
.950	3.6734E-01	2.7554E-01	2.1450E-02	1.0316E-01	2.8133E-01	1.1573E+00	1.4769E+00	9.0739E+01	[illegible]
1.000	3.4878E-01	2.6147E-01	0.	9.9243E-02	2.8469E-01	0.	0.	9.4679E+01	3.0785E-01

X	C_L	α_i	f_{M20}/C	C_D/C_L	F	L	C_{LE}/R	C_{TE}/R	t/R	$C_{P_{MIN}}$
.231	0.	0.	0.	0.	0.	1.	-3.170E-01	3.170E-01	6.587E-02	2.590E-01
.250	1.254E-01	1.936E-01	8.511E-03	5.217E-02	[illegible]	6.324E+02	-3.243E-01	3.357E-01	6.448E-02	3.197E-01
.300	2.038E-01	3.139E-01	1.386E-02	3.062E-02	2.020E-01	1.322E+03	-3.360E-01	3.860E-01	6.079E-02	3.349E-01
.400	2.333E-01	3.592E-01	1.584E-02	2.474E-02	2.223E-01	2.432E+03	-3.514E-01	4.746E-01	5.352E-02	3.023E-01
.500	[illegible]	3.401E-01	1.494E-02	2.463E-02	2.215E-01	3.491E+03	-3.439E-01	5.681E-01	4.624E-02	2.596E-01
.600	[illegible]	3.162E-01	1.385E-02	2.564E-02	2.211E-01	4.465E+03	-2.973E-01	6.465E-01	3.926E-02	2.267E-01
.700	1.872E-01	2.883E-01	1.271E-02	2.719E-02	2.215E-01	5.234E+03	-2.130E-01	7.127E-01	3.166E-02	1.981E-01
.800	1.709E-01	2.632E-01	1.161E-02	2.943E-02	2.226E-01	5.572E+03	-8.643E-02	7.679E-01	2.429E-02	1.743E-01
.900	1.538E-01	2.368E-01	1.044E-02	3.316E-02	2.196E-01	5.002E+03	9.837E-02	7.811E-01	1.720E-02	1.555E-01
.950	1.522E-01	2.344E-01	1.034E-02	3.508E-02	2.252E-01	3.955E+03	2.409E-01	7.421E-01	1.346E-02	1.590E-01
1.000	0.	0.	0.	0.	0.	0.	5.545E-01	5.545E-01	0.	7.350E-02

C_{PTI} = 7.4966E-01 C_{PSI} = 9.9391E-01 η_I = 7.5427E-01 C_{ThSI} = 7.7453E-01 C_{ThSI}/C_{PSI} = 7.7928E-01
C_{PT} = 7.3793E-01 C_{PS} = 1.0515E+00 η = 7.0181E-01 C_{ThS} = 7.6247E-01 C_{ThS}/C_{PS} = 7.2514E-01

η_D=.6[illegible] P_D(HP)=[illegible]E+03 1 - t =.8300 1 - W = .9698 V(KNOTS) = 14.007 DESIGN THR(LBF)=6.3490E+04
Z= [illegible] N(RPM)=13[illegible] A_E/A_0= .7759 V(FT/SEC) = 25.127 CALCULATED THR(LBF)=6.3592E+04

TABLE 5 - LIFTING-LINE CALCULATIONS AT ENDURANCE CONDITION

T-ARC OUTBOARD TURNING PROP **** FINAL DESIGN ****

P_D (HP) = 5.00..E+03, DENSITY OF PROP(LBM/FT3) = 668.293

V (KNOTS) =	1.3800E+01	1.4800E+01	1.5600E+01	1.6030E+01	1.7800E+01
PE (HP) =	1.5665E+03	1.9976E+03	2.4655E+03	3.3375E+03	3.7910E+03
Z =	4				
A_E/A_0 =	7.7589E-01				
N (RPM) =	1.4560E+02				

D = 13.000 ,1 - W_T = .9700 ,1 - t=.8300 ,H (FT) = 49.4100 ,ρ (SLUG/FT^3) = 1.9905

X INPUT	$1 - W_X$ INPUT	c/D INPUT	t/c INPUT	tan β_i (PREL)	tan β CALCULATED	θ_s (deg)	Z_R	x tan β_i	C_D INPUT
.231	1.0038E+00	3.1700E-01	1.0390E-01	1.6674E+00	1.2135E+00	-5.6043E-14	0.	1.1665E+00	6.6800E-03
.250	1.0205E+00	3.3060E-01	9.7700E-02	1.4469E+00	1.0553E+00	7.4122E-01	0.	1.1364E+00	6.5600E-03
.300	1.0149E+00	3.5900E-01	8.4980E-02	1.2607E+00	8.7204E-01	2.6918E+00	0.	1.1316E+00	6.2400E-03
.400	9.9725E-01	4.1300E-01	6.4800E-02	8.9644E-01	6.3951E-01	6.5930E+00	0.	1.1190E+00	5.7700E-03
.500	9.7990E-01	4.5600E-01	5.6730E-02	7.8616E-01	5.0275E-01	1.0494E+01	0.	1.1092E+00	5.4400E-03
.600	9.6743E-01	4.7100E-01	4.1600E-02	5.8457E-01	4.1342E-01	1.4395E+01	0.	1.1019E+00	5.2300E-03
.700	9.5947E-01	4.6200E-01	3.4260E-02	4.9909E-01	3.5159E-01	1.8296E+01	0.	1.0976E+00	5.0900E-03
.800	9.6035E-01	4.2460E-01	2.8600E-02	4.3695E-01	3.0799E-01	2.2190E+01	0.	1.0982E+00	5.0300E-03
.900	9.5839E-01	3.4130E-01	2.5280E-02	3.8797E-01	2.7315E-01	2.6099E+01	0.	1.0973E+00	5.1000E-03
.958	9.5731E-01	2.4659E-01	2.7300E-02	3.6734E-01	2.5848E-01	2.8049E+01	0.	1.0963E+00	5.3600E-03
1.000	9.5623E-01	0.	2.9460E-02	3.4878E-01	2.4528E-01	3.0000E+01	0.	1.0957E+00	5.5800E-03

X	tan β_i	tan β	G	U_T/V	U_A/V	$d(C_{ThSI})$	$d(C_{psi})$	V_r	σ
.231	1.6674E+00	1.2795E+00	0.	1.2429E-01	7.7942E-02	0.	0.	3.6828E+01	2.7734E+00
.250	1.4469E+00	1.1219E+00	9.1119E-03	1.3011E-01	9.8092E-02	1.1352E-01	1.5057E-01	3.6861E+01	2.2049E+00
.300	1.2607E+00	9.2712E-01	1.7493E-02	1.4583E-01	1.2587E-01	2.6700E-01	3.5274E-01	4.0134E+01	1.9235E+00
.400	8.9644E-01	6.7958E-01	2.7256E-02	1.5176E-01	1.7369E-01	5.7346E-01	7.4898E-01	4.7393E+01	1.3436E+00
.500	7.8616E-01	5.3450E-01	3.3383E-02	1.4735E-01	2.1369E-01	9.0868E-01	1.1660E+00	5.5558E+01	9.6281E-01
.600	5.8457E-01	4.3553E-01	3.6918E-02	1.3864E-01	2.3917E-01	1.2174E+00	1.5657E+00	6.4273E+01	7.8876E-01
.700	4.9909E-01	3.7379E-01	3.7908E-02	1.2044E-01	2.5751E-01	1.4790E+00	1.8967E+00	7.3392E+01	5.3621E-01
.800	4.3695E-01	3.2744E-01	3.5797E-02	1.1772E-01	2.6942E-01	1.6120E+00	2.0673E+00	8.2709E+01	4.1596E-01
.900	3.8797E-01	2.9840E-01	2.8844E-02	1.0849E-01	2.7991E-01	1.4730E+00	1.8860E+00	9.2147E+01	3.2953E-01
.950	3.6734E-01	2.7481E-01	2.1686E-02	1.0427E-01	2.8404E-01	1.1726E+00	1.5085E+00	9.6990E+01	2.9613E-01
1.000	3.4878E-01	2.6077E-01	0.	1.0031E-01	2.8773E-01	0.	0.	1.0147E+02	2.6697E-01

X	C_L	α_i	f_{M2D}/C	C_D/C_L	F	L	C_{LE}/R	C_{TE}/R	t/R	$C_{P_{MIN}}$
.231	0.	0.	0.	0.	0.	0.	-3.170E-01	3.170E-01	6.587E-02	2.598E-01
.250	1.267E-01	1.951E-01	8.682E-03	5.162E-02	1.402E-01	7.349E+02	-3.243E-01	3.357E-01	6.448E-02	3.285E-01
.300	2.059E-01	3.171E-01	1.398E-02	3.031E-02	2.022E-01	1.536E+03	-3.363E-01	3.808E-01	6.379E-02	3.361E-01
.400	2.355E-01	3.627E-01	1.599E-02	2.450E-02	2.223E-01	2.826E+03	-3.514E-01	4.746E-01	5.352E-02	3.037E-01
.500	2.228E-01	3.432E-01	1.513E-02	2.441E-02	2.215E-01	4.058E+03	-3.439E-01	5.681E-01	4.624E-02	2.698E-01
.600	2.056E-01	3.165E-01	1.397E-02	2.541E-02	2.211E-01	5.191E+03	-2.973E-01	6.465E-01	3.926E-02	2.278E-01
.700	1.888E-01	2.908E-01	1.282E-02	2.698E-02	2.215E-01	6.084E+03	-2.130E-01	7.127E-01	3.166E-02	1.991E-01
.800	1.724E-01	2.654E-01	1.170E-02	2.918E-02	2.226E-01	6.478E+03	-8.643E-02	7.629E-01	2.429E-02	1.752E-01
.900	1.551E-01	2.388E-01	1.053E-02	3.249E-02	2.196E-01	5.816E+03	9.837E-02	7.811E-01	1.720E-02	1.563E-01
.950	1.535E-01	2.364E-01	1.042E-02	3.479E-02	2.252E-01	4.598E+03	2.489E-01	7.421E-01	1.346E-02	1.606E-01
1.000	0.	0.	0.	0.	0.	0.	5.545E-01	5.545E-01	0.	7.353E-02

C_{PTI} = 7.5961E-01	C_{PSI} = 1.0097E+00	η_I = 7.5225E-01	C_{ThSI} = 7.8469E-01	C_{ThSI}/C_{PSI} = 7.7719E-01
C_{PT} = 7.4772E-01	C_{PS} = 1.0676E+00	η = 7.0035E-01	C_{ThS} = 7.7258E-01	C_{ThS}/C_{PS} = 7.2364E-01

R_H = .0..E P_D(HP) = 4.9996E+03   1 - t = .8300   1 - W = .9695   V(KNOTS) = 15.947   DESIGN TH(LBF)=7.3926E+04
Z = 4   N(RPM) = 145.00 A_E/A_0 = .7759   V(FT/SEC) = 26.916   CALCULATED TH(LBF)=7.3930E+04

TABLE 6 - LIFTING-SURFACE CALCULATIONS AT FULL-POWER CONDITION

PROPELLER BLADE SECTION DESIGN FOR PRESCRIBED LOAD DISTRIBUTION
MIT-PBD-9

T-AGC OUTBOARD TURNING PROP Z=4 AR=.7759 RPM=145 *FINAL* 3 21 79

DIAMETER-IN	156.00	CHORD LOAD TYPE	56 CHORDWISE PANELS
HUB DIAM-IN	36.00	NACA A= .80	48 RADIAL S-V LINES
NO.OF BLADES	4		WITH 2 DEG SPACING
REVS PER MIN	145.00	THICKNESS FORM	WAKE ANGLE RATIO=1.0
SPEED-VS-KTS	15.95	NSRDC MOD NACA 66	HUB IMAGE IS ABSENT

R/RO	TAN BS	TAN B	SL/RO	ST/RO	GAMMA	G COEFFS	VA/VS	UA*/VS	TO/RO	RK/RO
.2788	1.2916	1.0002	-.[illegible]	.3618	.0158	.03728E	1.022	.1155	.0623	0.0000
.3269	1.0972	.8464	-.3416	.4051	.0209	-.003586	1.014	.1399	.0588	0.0000
.4231	.8394	.6405	-.3526	.4973	.0290	.000246	.993	.1833	.0518	0.0000
.5192	.6788	.5136	-.3378	.5843	.0343	.000090	.977	.2168	.0449	0.0000
.6154	.5694	.4281	-.2867	.6575	.0373	.000286	.965	.2417	.0381	0.0000
.7115	.4910	.3581	-.1998	.7186	.0378	0.000000	.960	.2593	.0308	0.0000
.8077	.4328	.3245	-.0721	.7634	.0351	0.000000	.960	.2748	.0234	0.0000
.9038	.3863	.2894	[illegible]71	.7808	.0286	0.000000	.958	.2804	.0170	0.0000
.9519	.3666	.2745	[illegible]570	.7384	.0212	0.000000	.957	.2843	.0132	0.0000
1.0000			.5545	.5545						

R/RO	P/D	C/D	FO/C	TO/C	ALPHA	R-IN	P-IN	C-IN	FO-IN	TO-IN	RK-IN
.2788	1.318	.347	.0318	.0898	11.38	21.75	205.55	54.12	1.722	4.86	0.00
.3269	1.264	.373	.0266	.0788	10.66	25.50	197.21	58.24	1.552	4.59	0.00
.4231	1.2[illegible]5	.425	.0205	.0610	9.57	33.00	188.05	66.28	1.357	4.04	0.00
.5192	1.191	.461	.0196	.0487	8.95	40.50	185.78	71.92	1.412	3.50	0.00
.6154	1.174	.472	.0204	.0403	8.08	48.00	183.08	73.65	1.502	2.97	0.00
.7115	1.151	.459	.0215	.0335	7.03	55.50	179.51	71.63	1.542	2.40	0.00
.8077	1.130	.418	.0228	.0280	6.03	63.00	176.30	65.17	1.488	1.83	0.00
.9038	1.087	.337	.0234	.0253	4.81	70.50	169.54	52.55	1.230	1.33	0.00
.9519	1.057	.241	.0279	.0274	4.12	74.25	164.92	37.54	1.047	1.03	0.00

TABLE 7 - EXPERIMENTAL AND LIFTING-LINE PERFORMANCE PREDICTIONS

	Experimental Predictions		Lifting-Line Predictions		
				Revised Prediction Using Final Hull Data and Design Propeller $\tan\beta_i$	
	Preliminary Hull with Stock Propellers (Propeller Design Information)	Final Hull with Design Propellers	Design Propeller Using Preliminary Hull with Stock Propeller Data and Full-Scale Blade Drag	Using Full-Scale Blade Drag	Using Model-Scale Blade Drag for Comparison to Tests
V (knots)	≈16	16.7	15.95	16.63	16.33
P_D per shaft	5,000	5,000	5,000	5,000	5,000
P_E per shaft (at design speed)	2,950	3,250	3,065	3,280	3,045
n	≈152	140	145	144	141
η_D	≈.59	0.65	0.608	0.656	0.609
(1-t)	0.83	0.864	0.83	0.864	0.864
$(1-w_T)$	0.97	0.921	0.97	0.921	0.921
$C_{D_{0.7}}$	--	--	0.005	0.005	0.011
P_E per shaft (at 16 knots)	3,038	2,844	3,038	2,844	2,844
Reference Column	1	2	3	4	5

TABLE 8 - FINAL LIFTING-LINE CALCULATIONS AT FULL-POWER CONDITION

T-ARC PROPELLER INCREASED THICKNESS 11/27/80

P_D(HP) = 5.3000E+03, DENSITY OF PROP(LBM/FT3) = 460.2900

V(KNOTS) = 1.3000E+01 1.4000E+01 1.5000E+01 1.6000E+01 1.7000E+01
PE(HP) = 1.5665E+03 1.9970E+03 2.4655E+03 3.0375E+03 3.7910E+03

D = 3.3000, 1 - W_T = .9700, 1 - t = .8300, H(FT) = 49.4100, ρ(SLUG/FT^3) = 1.9905

Z = 4
A_E/A_O = 7.7589E-01
N(RPM) = 1.3000E+02 1.3500E+02 1.4000E+02 1.4500E+02

X INPUT	1 - W_X INPUT	c/D INPUT	t/c INPUT	tan β_i (PREL)	tan β CALCULATED	θ_s (deg)	Z_R	$\pi x \tan \beta_i$	C_D INPUT
2.3100E-01	1.0006E+00	3.1700E-01	1.2800E-01	1.6874E+00	1.1197E+00	0.	0.	0.	6.9900E-03
2.5000E-01	1.0285E+00	3.3000E-01	1.1900E-01	1.4469E+00	1.0553E+00	7.4122E-01	0.	0.	6.7700E-03
3.0000E-01	1.0199E+00	3.9706E-01	1.0300E-01	1.2[illegible]7E+00	8.7254E-01	2.6910E+00	0.	0.	6.4100E-03
4.0000E-01	9.9725E-01	4.1300E-01	7.9900E-02	8.9044E-01	6.3951E-01	6.5930E+00	0.	0.	5.8000E-03
5.0000E-01	9.7990E-01	4.5600E-01	6.1000E-02	7.0616E-01	5.0275E-01	1.0494E+01	0.	0.	5.5100E-03
6.0000E-01	9.6703E-01	4.7100E-01	5.0000E-02	5.8457E-01	4.1342E-01	1.4395E+01	0.	0.	5.2000E-03
7.0000E-01	9.5947E-01	4.6206E-01	4.1000E-02	4.9989E-01	3.5159E-01	1.8296E+01	0.	0.	5.1300E-03
8.0000E-01	9.6055E-01	4.2466E-01	3.4000E-02	4.3595E-01	3.0799E-01	2.2198E+01	0.	0.	5.0600E-03
9.0000E-01	9.5039E-01	3.4136E-01	2.9000E-02	3.8797E-01	2.7315E-01	2.6099E+01	0.	0.	5.1100E-03
9.5000E-01	9.5731E-01	2.4659E-01	3.0000E-02	3.6734E-01	2.5848E-01	2.8049E+01	0.	0.	5.3500E-03
1.0000E+00	9.5623E-01	0.	9.5400E-02	3.4878E-01	2.4520E-01	3.0000E+01	0.	0.	5.5900E-03

X	tan β_i	tan β	G	U_T/V	U_A/V	d(C_{ThSI})	d(C_{psi})	V_r	σ
2.3100E-01	1.6874E+00	1.1942E+00	0.	1.5826E-01	9.9873E-02	0.	0.	3.5699E+01	2.5036E+00
2.5000E-01	1.4469E+00	1.1217E+00	9.1480E-03	1.3823E-01	9.8179E-02	1.1397E-01	1.5121E-01	3.6056E+01	2.2695E+00
3.0000E-01	1.2807E+00	9.7693E-01	1.7557E-02	1.4595E-01	1.2590E-01	2.6900E-01	3.5417E-01	4.0130E+01	1.9039E+00
4.0000E-01	8.9044E-01	6.7976E-01	2.7333E-02	1.5108E-01	1.7304E-01	5.7517E-01	7.5136E-01	4.7309E+01	1.3430E+00
5.0000E-01	7.0616E-01	5.3439E-01	3.3420E-02	1.4747E-01	2.1086E-01	9.0172E-01	1.1677E+00	5.5555E+01	9.6292E-01
6.0000E-01	5.8457E-01	4.3944E-01	3.6944E-02	1.3875E-01	2.3026E-01	1.2100E+00	1.5678E+00	6.4270E+01	7.0802E-01
7.0000E-01	4.9989E-01	3.7372E-01	3.7937E-02	1.2854E-01	2.5772E-01	1.4803E+00	1.8968E+00	7.3350E+01	5.3625E-01
8.0000E-01	4.3695E-01	3.2737E-01	3.5814E-02	1.1782E-01	2.7004E-01	1.6130E+00	2.0690E+00	8.2707E+01	4.1560E-01
9.0000E-01	3.8797E-01	2.9034E-01	2.8844E-02	1.0858E-01	2.6813E-01	1.4733E+00	1.8667E+00	9.2145E+01	3.2995E-01
9.5000E-01	3.6734E-01	2.7475E-01	2.1683E-02	1.0435E-01	2.6427E-01	1.1726E+00	1.5000E+00	9.6898E+01	2.9614E-01
1.0000E+00	3.4878E-01	2.6072E-01	0.	1.0078E-01	2.0796E-01	0.	0.	1.0167E+02	2.6690E-01

C_{PTI} = 7.6030E-01 C_{PSI} = 1.0109E+00 η_I = 7.5211E- C_{ThSI} = 7.8550E-01 C_{ThSI}/C_{PSI} = 7.7703E-01
C_{PT} = 7.4830E-01 C_{PS} = 1.0693E+00 η = 6.9987E- C_{ThS} = 7.7325E-01 C_{ThS}/C_{PS} = 7.2313E-01

X	C_L	α_i	f_{M2D}/C	C_D/C_L	F	L	C_{LE}/R	C_{TE}/R	t/R	$C_{P_{MIN}}$
2.310E-01	0.	0.	0.	0.	0.	0.	0.	-3.170E-01	3.170E-01	9.115E-02
2.500E-01	1.272E-01	1.959E-01	8.635E-03	5.323E-02	1.409E-01	7.376E+02	7.412E-01	-3.243E-01	3.357E-01	7.854E-02
3.000E-01	2.066E-01	3.192E-01	1.445E-02	3.112E-02	2.024E-01	1.541E+03	2.892E+00	-3.364E-01	3.806E-01	7.375E-02
4.000E-01	2.361E-01	3.636E-01	1.607E-02	2.490E-02	2.726E-01	2.834E+03	6.593E+00	-3.514E-01	4.746E-01	6.525E-02
5.000E-01	2.231E-01	3.435E-01	1.515E-02	2.470E-02	2.716E-01	4.062E+03	1.049E+01	-3.479E-01	5.681E-01	5.563E-02
6.000E-01	2.060E-01	3.172E-01	1.399E-02	2.564E-02	2.211E-01	5.1[illegible]4E+03	1.440E+01	-2.973E-01	6.465E-01	4.719E-02
7.000E-01	1.889E-01	2.910E-01	1.283E-02	2.715E-02	2.215E-01	6.[illegible]E+03	1.830E+01	-2.130E-01	7.127E-01	3.795E-02
8.000E-01	1.724E-01	2.655E-01	1.171E-02	2.935E-02	2.225E-01	6.4[illegible]E+03	2.220E+01	-8.643E-02	7.629E-01	2.888E-02
9.000E-01	1.550E-01	2.388E-01	1.053E-02	3.296E-02	2.195E-01	5.814E+03	2.610E+01	9.837E-02	7.811E-01	1.912E-02
9.500E-01	1.534E-01	2.363E-01	1.042E-02	3.487E-02	2.250E-01	4.596E+03	2.805E+01	2.469E-01	7.421E-01	1.480E-02
1.000E+00	0.	0.	0.	0.	0.	0.	3.000E+01	5.545E-01	5.545E-01	0.

η_D=6.8820E-01 P_D(HP)=4.9996E+03 1 - t=8.3000E-01 1 - W=9.7000E-01 V(KNOTS) = 1.5944E+01 DESIGN TH(LBF)=7.3809E+04
Z= 4 N(RPM)=1.4500E+02 A_E/A_0=7.7589E-01 V(FT/SEC) = 2.6910E+01 CALCULATED TH(LBF)=7.3973E+04

TABLE 9 - FINAL LIFTING-LINE CALCULATIONS AT ENDURANCE CONDITION

T-ARC PROPELLER   INCREASED THICKNESS   11/27/80

P_D(HP) = 4.0000E+03, DENSITY OF PROP(LBM/FT3) = 460.2960

V(KNOTS) =	1.3000E+01	1.4000E+01	1.5000E+01	1.6000E+01	1.7000E+01
PE(HP) =	1.5665E+03	1.9970E+03	2.4655E+03	3.0375E+03	3.7910E+03

D = 13.0000, $1 - w_T$ = .9700, $1 - t$ = .8300, H(FT) = 49.4100, ρ(SLUG/FT^3) = 1.9905

Z = 4
A_E/A_O = 7.7589E-01
N(RPM) = 1.3000E+02   1.3500E+02   1.4000E+02   1.4500E+02

X INPUT	$1 - w_x$ INPUT	c/D INPUT	t/c INPUT	$\tan \beta_1$ (PREL)	$\tan \beta$ CALCULATED	θ_s (deg)	Z_R	$\pi x \tan \beta_1$	C_D INPUT
2.3100E-01	1.0004E+00	3.1700E-01	1.2800E-01	1.6074E+00	1.2027E+00	0.	0.	0.	6.9900E-03
2.5000E-01	1.0285E+00	3.3000E-01	1.1960E-01	1.4469E+00	1.1334E+00	7.4122E-01	0.	0.	6.7700E-03
3.0000E-01	1.0199E+00	3.5800E-01	1.0300E-01	1.2007E+00	9.3664E-01	2.6910E+00	0.	0.	6.4100E-03
4.0000E-01	9.9725E-01	4.1300E-01	7.9000E-02	6.9044E-01	6.8668E-01	6.5930E+00	0.	0.	5.8800E-03
5.0000E-01	9.7990E-01	4.5600E-01	6.1000E-02	7.4616E-01	5.3999E-01	1.0494E+01	0.	0.	5.5100E-03
6.0000E-01	9.6733E-01	4.7198E-01	5.0000E-02	5.8457E-01	4.4404E-01	1.4395E+01	0.	0.	5.2800E-03
7.0000E-01	9.5967E-01	4.6286E-01	4.1000E-02	4.9909E-01	3.7763E-01	1.8296E+01	0.	0.	5.1300E-03
8.0000E-01	9.6855E-01	4.2466E-01	3.4000E-02	4.3695E-01	3.3080E-01	2.2198E+01	0.	0.	5.0600E-03
9.0000E-01	9.5839E-01	3.4176E-01	2.8000E-02	3.8797E-01	2.9330E-01	2.6099E+01	0.	0.	5.1100E-03
9.5000E-01	9.5731E-01	2.4659E-01	3.0000E-02	3.6734E-01	2.7763E-01	2.8049E+01	0.	0.	5.3500E-03
1.0000E+00	9.5623E-01	0.	9.5000E-02	3.4878E-01	2.6345E-01	3.0000E+01	0.	0.	5.5900E-03

X	$\tan \beta_1$	$\tan \beta$	G	U_T/V	U_A/V	$d(C_{ThSI})$	$d(C_{psi})$	V_r	σ
2.3100E-01	1.6074E+00	1.1934E+00	0.	1.5664E-01	9.8065E-02	0.	0.	3.7735E+01	2.8775E+00
2.5000E-01	1.4469E+00	1.1247E+00	9.0440E-03	1.3660E-01	9.7026E-02	1.1756E-01	1.4894E-01	3.4370E+01	2.6096E+00
3.0000E-01	1.2037E+00	9.2539E-01	1.7359E-02	1.4426E-01	1.2457E-01	2.6473E-01	3.4881E-01	3.7414E+01	2.1903E+00
4.0000E-01	8.9044E-01	6.8156E-01	2.7832E-02	1.5019E-01	1.7189E-01	5.6788E-01	7.3988E-01	4.4165E+01	1.5471E+00
5.0000E-01	7.0616E-01	5.3581E-01	3.3057E-02	1.4587E-01	2.0857E-01	8.9023E-01	1.1498E+00	5.1761E+01	1.1692E+00
6.0000E-01	5.9457E-01	4.4061E-01	3.6549E-02	1.3727E-01	2.3572E-01	1.2232E+00	1.5637E+00	5.9870E+01	8.1683E-01
7.0000E-01	4.9909E-01	3.7471E-01	3.7534E-02	1.2719E-01	2.5588E-01	1.4614E+00	1.8676E+00	6.8319E+01	6.1812E-01
8.0000E-01	4.3695E-01	3.2824E-01	3.5436E-02	1.1657E-01	2.6719E-01	1.5931E+00	2.0378E+00	7.7029E+01	4.7922E-01
9.0000E-01	3.8797E-01	2.9111E-01	2.6540E-02	1.0744E-01	2.7719E-01	1.4543E+00	1.8575E+00	6.5814E+01	3.8043E-01
9.5000E-01	3.6734E-01	2.7540E-01	2.1454E-02	1.0326E-01	2.8129E-01	1.1574E+00	1.4775E+00	9.0237E+01	3.4148E-01
1.0000E+00	3.4878E-01	2.6141E-01	0.	9.9333E-02	2.8495E-01	0.	0.	9.4678E+01	3.0786E-01

C_{PTI} = 7.5057E-01 C_{PSI} = 9.9532E-01 η_I = 7.5410E- C_{ThSI} = 7.7544E-01 C_{ThSI}/C_{PSI} = 7.7909E-01
C_{PT} = 7.3869E-01 C_{PS} = 1.0533E+00 η = 7.0131E- C_{ThS} = 7.6324E-01 C_{ThS}/C_{PS} = 7.2462E-01

X	C_L	α_1	f_{M2D}/C	C_D/C_L	F	L	C_{LE}/R	C_{TE}/R	t/R	$C_{P_{MIN}}$
2.310E-01	0.	0.	0.	0.	1.	0.	0.	-3.170E-01	3.170E-01	8.115E-02
2.500E-01	1.259E-01	1.938E-01	8.546E-03	5.379E-02	1.484E-01	6.348E+02	7.412E-01	-3.243E-01	3.357E-01	7.854E-02
3.000E-01	2.046E-01	3.158E-01	1.309E-02	3.134E-02	2.025E-01	1.326E+03	2.092E+00	-3.360E-01	3.800E-01	7.375E-02
4.000E-01	2.339E-01	3.602E-01	1.580E-02	2.514E-02	2.226E-01	2.430E+03	6.593E+00	-3.514E-01	4.740E-01	6.525E-02
5.000E-01	2.211E-01	3.404E-01	1.501E-02	2.493E-02	2.216E-01	3.494E+03	1.049E+01	-3.479E-01	5.681E-01	5.563E-02
6.000E-01	2.042E-01	3.145E-01	1.386E-02	2.506E-02	2.211E-01	4.469E+03	1.440E+01	-2.973E-01	6.465E-01	4.719E-02
7.000E-01	1.873E-01	2.885E-01	1.272E-02	2.738E-02	2.215E-01	5.237E+03	1.830E+01	-2.130E-01	7.127E-01	3.795E-02
8.000E-01	1.710E-01	2.633E-01	1.161E-02	2.959E-02	2.225E-01	5.574E+03	2.220E+01	-8.643E-02	7.629E-01	2.880E-02
9.000E-01	1.538E-01	2.368E-01	1.044E-02	3.323E-02	2.195E-01	5.002E+03	2.610E+01	9.837E-02	7.811E-01	1.912E-02
9.500E-01	1.522E-01	2.344E-01	1.033E-02	3.515E-02	2.250E-01	3.954E+03	2.805E+01	2.489E-01	7.421E-01	1.480E-02
1.000E+00	0.	0.	0.	0.	0.	0.	3.000E+01	5.545E-01	5.545E-01	0.

η_D=6.6143E-01 P_D(HP) =4.0001E+03   1 - t =8.3000E-01   1 - W =9.7000E-01   V(KNOTS) = 1.4084E+01   DESIGN TH(LBF)=6.3459E+04
Z= 4   N(RPM) =1.3500E+02 A_E/A_O =7.7589E-01   V(FT/SEC) = 2.5121E+01   CALCULATED TH(LBF)=6.3628E+04

TABLE 10 - FINAL LIFTING-SURFACE CALCULATIONS AT FULL-POWER CONDITION

PROPELLER BLADE SECTION DESIGN FOR PRESCRIBED LOAD DISTRIBUTION
************************ MIT-PBD-9 ************************

T-ARC PROPELLER   INCREASED THICKNESS FOR PBD9   12/11/80

DIAMETER-IN	156.00	CHORD LOAD TYPE		56 CHORDWISE PANELS
HUB DIAM-IN	36.04	NACA A= .80		48 RADIAL S-V LINES
NO.OF BLADES	4			WITH 2 DEG SPACING
REVS PER MIN	145.00	THICKNESS FORM		WAKE ANGLE RATIO=1.0
SPEED-VS-KTS	15.94	NSRDC MOD NACA 66		HUB IMAGE IS ABSENT

R/RO	TAN BS	TAN B	SL/RO	ST/RO	GAMMA	G COEFFS	VA/VS	UA*/VS	TO/RO	RK/RO
.2791	1.2822	1.0070	-.3320	.3619	.0159	.037303	1.030	.1113	.0755	0.0000
.3271	1.0471	.8456	-.3416	.4051	.0209	-.003561	1.014	.1400	.0714	0.0000
.4233	.8393	.6400	-.3526	.4973	.0290	.000248	.993	.1834	.0630	0.0000
.5194	.6767	.5133	-.3378	.5843	.0343	.000996	.977	.2169	.0547	0.0000
.6155	.5693	.4279	-.2867	.6575	.0373	.000283	.965	.2418	.0458	0.0000
.7116	.4909	.3679	-.1998	.7196	.0378	0.000000	.960	.2594	.0369	0.0000
.8077	.4327	.3244	-.0721	.7634	.0351	0.000000	.960	.2709	.0277	0.0000
.9039	.3863	.2893	.1071	.7818	.0285	0.000000	.959	.2835	.0189	0.0000
.9519	.3666	.2744	.2570	.7364	.0212	0.000000	.957	.2844	.0145	0.0000
1.0000			.5545	.5545						

R/RO	P/D	C/D	FO/C	TO/C	ALPHA	R-IN	P-IN	C-IN	FO-IN	TO-IN	RK-IN
.2791	1.337	.347	.0315	.1098	11.56	21.77	208.65	54.12	1.736	5.89	0.00
.3271	1.272	.373	.0264	.0957	10.85	25.52	198.46	58.24	1.539	5.57	0.00
.4233	1.213	.425	[illegible]	.0741	9.75	33.01	189.19	66.29	1.346	4.91	0.00
.5194	1.196	.461	.0195	.0586	9.08	40.51	186.63	71.92	1.400	4.21	0.00
.6155	1.177	.472	.0203	.0485	8.17	48.01	183.68	73.65	1.495	3.57	0.00
.7116	1.154	.459	.0215	.0402	7.10	55.51	179.96	71.63	1.540	2.88	0.00
.8077	1.132	.418	.0228	.0332	6.07	63.00	176.62	65.17	1.488	2.16	0.00
.9039	1.088	.337	.0234	.0281	4.83	70.50	169.73	52.55	1.229	1.47	0.00
.9519	1.058	.241	.0279	.0301	4.14	74.25	165.04	37.54	1.046	1.13	0.00

DTNSRDC ISSUES THREE TYPES OF REPORTS

1. DTNSRDC REPORTS, A FORMAL SERIES, CONTAIN INFORMATION OF PERMANENT TECHNICAL VALUE. THEY CARRY A CONSECUTIVE NUMERICAL IDENTIFICATION REGARDLESS OF THEIR CLASSIFICATION OR THE ORIGINATING DEPARTMENT.

2. DEPARTMENTAL REPORTS, A SEMIFORMAL SERIES, CONTAIN INFORMATION OF A PRELIMINARY, TEMPORARY, OR PROPRIETARY NATURE OR OF LIMITED INTEREST OR SIGNIFICANCE. THEY CARRY A DEPARTMENTAL ALPHANUMERICAL IDENTIFICATION.

3. TECHNICAL MEMORANDA, AN INFORMAL SERIES, CONTAIN TECHNICAL DOCUMENTATION OF LIMITED USE AND INTEREST. THEY ARE PRIMARILY WORKING PAPERS INTENDED FOR INTERNAL USE. THEY CARRY AN IDENTIFYING NUMBER WHICH INDICATES THEIR TYPE AND THE NUMERICAL CODE OF THE ORIGINATING DEPARTMENT. ANY DISTRIBUTION OUTSIDE DTNSRDC MUST BE APPROVED BY THE HEAD OF THE ORIGINATING DEPARTMENT ON A CASE-BY-CASE BASIS.

DATE
ILME